AGRODEP Technical Note 0018

February 2021

# Measuring integration of agricultural markets

**Fousseini Traore**
**Insa Diop**

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## Abstract

The study of market integration offers a powerful tool for understanding the relationships between geographically distant markets, for analyzing the impact of liberalization policies and for diagnosing the transmission of price shocks. The literature on tools for measuring market integration, particularly those developed for agricultural markets, has been subject to major developments in terms of approaches over the past two decades. This technical note aims to provide an overview of the literature and tools for measuring agricultural markets integration, as well as their applications. The results should be interpreted with caution as these methods are in full development and must be linked to qualitative information that can support their validity.

# I. Introduction

In the recent 30 years, there has been an increasingly strong evolution in the literature on tools to measure markets integration, especially those of agricultural markets. This trend is part of a much larger framework which aims to promote integration or sub-regional, regional, even international economic association. For proponents of free trade, the more integrated the markets are, the better for price stability and the well-being of economic agents, as well as the absorption of systemic shocks[1] by domestic and regional markets (Ravallion, 1986, 1997; Sen 1981). On the other hand, for others, less optimistic, markets integration can lead to complex redistributive effects[2] (Newbery, Stiglitz, 1984; Bonjean and Combes, 2010). This framework demonstrates that the analysis of market integration is a powerful tool for analyzing the impact of liberalization policies, as well as the identification of regions exposed to systemic shocks.

However, the transition from the conceptual approach to markets integration to its measurement is very complex. This is reflected by the diversity of approaches and measurement tools. The most used approach to analyze markets integration is the price transmission mechanism of geographically distant areas.

One of the main reasons for this approach is statistical, while the other is conceptual. Most countries have one or more institutions intended to collect price data on a large set of products and a large set of markets with a very fine level of disaggregation and broad harmonization, as well as on a very short period (semi-annual, monthly, quarterly, etc.). This wide availability of price data favors the analysis of markets integration by prices in contrast to trade flows. However, the price data are tainted with imperfections. This can lead to questionable assumptions about product homogeneity and the treatment of some missing data. The conceptual reason is linked to the definition of a market which is nothing other than the physical or virtual place of confrontation between supply and demand of a product where equilibrium price is determined once the transaction costs considered (Stigler and Sherwin, 1985). The price transmission analysis is based on the Enke-Samuelson-Takayama-Judge (ESTJ) spatial equilibrium model (Enke, 1951; Samuelson, 1952; Takayama and Judge, 1971). This model assumes the free movement of products and perfect information between geographically distinct markets. However, two major approaches have been developed to analyze this model.

The first, that of the law of the one price (LOOP), is the analytical framework most used to test markets integration (Richardson, 1978; Crouhy-Veyrac and al 1982; Ravallion 1986; Carter and Hamilton 1989; Goodwin and Schroeder, 1991; Sexton and al., 1991). According to Dornbusch (1987), the law of the one price is consistent with the spatial integration of markets once transaction costs and real frictions are considered. The latter, in its relative version, stipulates that if there is trade in a product between two

[1] Food crisis in Niger in 2005

[2] Market integration is profitable for producers of exportable products who benefit from better remuneration for their products, but producers of import substitution products lose.

regions, the price of the importing region is equal to the price of the exporting region adjusted for transaction costs. This model adapts to short-term fluctuations but is compatible with convergence towards a long-term equilibrium if there are exchanges between the two markets (Vollrath and Hallahan, 2006). However, information flows between markets and networks of traders can also allow the transmission of price signals between markets in the absence of trade flows (Jensen, 2007; Fackler and Tastan, 2008, Stephens and al., 2008; Ihle and al., 2010).

The second, developed by McNew (1996), is based on an analysis of markets connectedness. This approach analyzes the dynamics of transmission of price shocks, especially the price adjustment process, while the model based on the law of the single price focuses on the price relationships between markets. The connectedness approach aims to measure the degree to which a price shock is transmitted from one region to another (McNew and Fackler, 1997). Besides, other approaches incorporate the mechanism by which upward and downward shocks are transmitted. This is the approach analyzing the asymmetry of price transmission (Balke and Fomby, 1997; von Cramon-Taubadel, 1998; Abdulaï, 2000; Goodwin and Piggott, 2001).

However, even if the approaches differ, they complement each other. One seeks to quantify a long-term cointegration relationship ensuring markets integration while the other seeks to identify and quantify the impacts of a shock from one market on the other and vice versa. A large empirical literature offers tools to measure markets integration that are both evolving and complementary. Two measurement tools emerge in the empirical literature. These are descriptive methods and econometric methods.

Despite the limits of descriptive methods, they offer a quick and succinct preliminary analysis of the relationships between prices in different markets while presenting certain problems that only an econometric study could detect. They are, moreover, the first tools used to analyze markets integration but still criticized due to their multiple problems, (Cummings, 1967 and Lele, 1971, Blyn 1973, Harriss, 1979). The flagship tool of descriptive methods used is the bivariate correlation. This method is attached with a well-known expression in statistics: "correlation is not causality". This warns of the use of correlation as a tool for assessing a relationship between two variables. A strong correlation between two price series can reveal a cause-and-effect link, but not necessarily.

The major successful challenge responding to the limitations of descriptive methods is the development of dynamic econometric methods after the 1980s. The approach developed by Ravallion (1986) is the basic dynamic model of markets integration. Indeed, the traditional static approach based on a regression on often non-stationary variables is associated with a fallacious regression problem and invalid statistical tests (Granger and Newbold, 1974). However, the literature on time series has supported the evolution of econometric methods measuring markets integration. This evolution highlights the development of the notions of causality (Granger, 1969; Sims, 1972; Johansen and Juselius, 1990; Phillips and Toda, 1993;

Toda and Yamamoto, 1995) and cointegration (Engle and Granger, 1987; Johansen, 1988). The application of these methodological advances has made it possible to use the VAR[3], ARDL[4] and VECM[5] models as tools to measure markets integration (Gupta and Mueller, 1982; Ravallion, 1986; Slade, 1986; Blank and Schmiesing, 1988; Alexander and Wyeth, 1994). These models, postulating the hypothesis of the stability of the linear model over time, have often been criticized. Indeed, due to structural change, certain parameters over time change continuously or discreetly. This questioning of the validity of linear econometric methods has pushed forward the analysis of regime change models (TAR[6], TVECM[7], PBM[8]), (Barrett, 1996; Baulch, 1997a; McNew and Fackler 1997, Miljkovic and Paul 2001, Ihle and al., 2010).

Considering this brief analysis of markets integration, this technical note proposes to give a detailed presentation of the tools to measure markets integration, as well as their applications while focusing on their limits and weaknesses. The plan adopted in this technical note consists to present the descriptive and econometric methods in section 1 and section 2 is reserved for the presentation of the data and the results about the application of the predefined tools, and finally ending with a conclusion.

## II. Different strategies to measure markets integration

This section presents a detailed description of the strategies to measure markets integration mostly used in the literature. The first part is devoted to the presentation of descriptive statistical methods, the second part is dedicated to presenting linear econometric methods and the last part of this section aims to present non-linear econometric methods to measure markets integration.

### *a. Descriptive statistical methods*

One of the first methods used to assess the degree of markets integration is correlation. This method is based on the idea that if two markets are perfectly competitive and spatially well integrated, then the difference between both prices of these two markets should only reflect the transaction costs, and the bivariate correlation must be equal to 1. Therefore, the more correlation is near to 1, the more markets are integrated.

There are two statistical approaches to measure correlation. The first is based on the parametric approach and the second on the non-parametric approach.

[3] 3Vector Auto-Regressive
[4] Auto-Regressive Distribution Lag
[5] Vector Error Correction Models
[6] Threshold Auto-Regressive
[7] Threshold Vector Error Correction Models
[8] Parity Bound Model

*i. Parametric approach*

This approach is based on the linear relationship assumption between the prices of the two markets.

*1. Pearson correlation*

If $P_{it}$ and $P_{jt}$ are the respective prices of markets i and j at period t, then the Pearson correlation is given by the relation below:

$$\rho = \frac{cov\left(P_{it}, P_{jt}\right)}{\sigma_{P_{it}} \sigma_{P_{jt}}}$$

$$\rho = \frac{\sum_{t=1}^{T}(P_{it} - \bar{P}_i)\left(P_{jt} - \bar{P}_j\right)}{\sqrt{\sum_{t=1}^{T}(P_{it} - \bar{P}_i)^2} * \sqrt{\sum_{t=1}^{T}\left(P_{jt} - \bar{P}_i\right)^2}} \tag{1}$$

If this correlation is statistically different from zero, then we cannot reject the hypothesis of the integration of the two markets.

So, to ensure the significance or not of the correlation, we must proceed to the Pearson test based on the T statistic defined below:

$$T_{(ddl=n-2)} = \frac{\rho}{S_\rho} = \frac{\rho}{\sqrt{\frac{1-\rho^2}{n-2}}} \tag{2}$$

*2. Limits*

In theory, the application of Pearson correlation as a measure of the degree of integration is only valid under the following assumptions: the existence of a linear relationship between both prices, the existence of a distribution asymptotically Gaussian, the absence of extreme values, and the homoscedasticity assumption. However, it is possible to diagnose these assumptions before using the Pearson correlation. The primary diagnoses are the graphic descriptions (scatter plot, histogram, and boxplot) to ensure a possible existence or not of a linear relation, the normality of the variables, the presence of a trend, and the absence of extreme values. The validation tests of these hypotheses can be done by using parametric and non-parametric tests. Even if the bivariate Pearson correlation is one of the most used methods, alternative methods with soft assumptions like the Spearman and Kendall correlation based on the nonparametric approach could be used.

*ii. Non-parametric approach*

Compared to the parametric approach, this does not require postulating a linear relationship hypothesis, an asymptotic normal distribution, as well as the absence of extreme values. The non-parametric approach is based on the rank of the observations.

*1. Spearman correlation*

Psychologist Charles Spearman proposed in 1904 the mostly used nonparametric method to measure the degree of connection between two variables, each presenting an order relation.

The basic idea of this method is that if the variables $P_{it}$ and $P_{jt}$ are perfectly linked in a positive or negative way, then the ranks $rg_{tP_{it}}$ *and* $rg_{P_{jt}}$ are perfectly correlated respectively.

Spearman's correlation is given by the following relation:

$$\rho_S = \frac{cov\left(rg_{P_{it}}, rg_{P_{jt}}\right)}{\sigma_{rgP_{it}}\sigma_{rgP_{jt}}}$$

$$\rho_S = 1 - 6\frac{\sum\left(rg_{P_{it}} - rg_{P_{jt}}\right)^2}{n(n^2-1)} \tag{3}$$

To find out if the value of $\rho_S$ is statistically different from zero, we can refer to Spearman's table. However, if the number of observations is greater than 30, the Student T statistic can be used:

$$T_{(ddl=n-2)} = \frac{\rho_S}{\sqrt{\frac{1-\rho_S{}^2}{n-2}}} \tag{4}$$

*2. Kendall's correlation*

Spearman's correlation only depends on rank distances. This dependence leads to the sensitivity of the Spearman correlation coefficient to extreme values and to small samples. On this, the correlation coefficient is less robust than the Kendall correlation coefficient in the case of small samples and the presence of extreme values.

The theoretical approach of the Kendall correlation coefficient is based on the idea presented below:

If $\forall\,(t_1, t_2)\ P\left((P_{it_1} - P_{it_2})(P_{jt_1} - P_{jt_2}) > 0\right) > \frac{1}{2}$ , then there is a good chance of observing a strong correlation between the variables $P_{it}$ and $P_{jt}$.

The theoretical Kendall correlation is defined by:

$$\tau = 2 * P\left((P_{it_1} - P_{it_2})(P_{jt_1} - P_{jt_2}) > 0\right) - 1$$

$$\tau = P\left((P_{it_1} - P_{it_2})(P_{jt_1} - P_{jt_2}) > 0\right) - P\left((P_{it_1} - P_{it_2})(P_{jt_1} - P_{jt_2}) < 0\right) \tag{5}$$

$$\tau = Prob_{Concordance} - Prob_{discordance}$$

On two independent samples of n observations the Kendall rate is given by:

$$\tau = \frac{S}{n(n-1)} \tag{6}$$

Where S is the difference between the number of identical rankings $\left((\mathrm{P}_{\mathrm{it}_1} - \mathrm{P}_{\mathrm{it}_2})(\ \mathrm{P}_{\mathrm{jt}_1} - \mathrm{P}_{\mathrm{jt}_2}) > 0\right)$ and the number of reverse rankings $\left((\mathrm{P}_{\mathrm{it}_1} - \mathrm{P}_{\mathrm{it}_2})(\ \mathrm{P}_{\mathrm{jt}_1} - \mathrm{P}_{\mathrm{jt}_2}) < 0\right)$.

To test the significance of the Kendall rate, we can use the Kendall rate approximation as a Laplace Gauss law which is judged to be very good as soon as n> = 2.

$$\tau \sim LG\left(0;\ \sqrt{\frac{2(2n+5)}{9n(n-1)}}\right) \tag{7}$$

Non-parametric methods are very useful when the distributions of the variables are not normal, as well as in situations where the data have extreme values, as are small samples either. They are more robust and less sensitive to extreme values.

However, a graphical diagnosis is often necessary to ensure the existence of a monotonous relation of the distributions, but also the transformation of the continuous variables into ordinal variables can distort the direction of the connection between the two variables.

It is also important to note that descriptive methods do not take into account lagged information that may better explain the relationship, as well as omitted variables (inflation, common periodicity, seasonality, climate shocks) that may cause spurious integration due to common exogenous trends.

### *b. Linear econometric methods*

Classic econometrics were often based on questionable assumptions (stationarity, cointegration, exogeneity). Recent developments in the theory and application of time series have provided many test tools to validate certain hypotheses (stationarity, cointegration, causality, etc.). This part consists of presenting recent econometric methods (linear methods) applicable to market integration.

Ravallion (1986) developed a model based on the existence of a central (reference) market and n regional markets. This model is formalized as follows:

$$P_{it} = a_0 + \sum_{j=1}^{n} a_{ij} P_{it-j} + \sum_{j=0}^{n} b_{ij} P_{ct-j} + d_i X_{it} + \epsilon_{it} \tag{8}$$

Where $P_c$ is the central market price; $P_i$ (i = 2… n), the regional market price; $X_i$, the exogenous factors (seasonality, inflation, …) that can influence the market price i.

Following Ravallion (1986), the following hypotheses can be tested:

- **Market segmentation**: central (leader) market prices do not influence the ith market prices: $b_{ij} = 0,\ j = 0,1, \dots n$
- **(Long run) market integration** given by the long run equilibrium of (E): $\sum_{j=1}^{n} a_{ij} + \sum_{j=0}^{n} b_{ij} = 1$

Linear econometric methods are the most widely used methods in time series econometrics. Their strong use is due to their capacity to make the formalization of complex economic phenomena simple and interpretable. In this context, market integration is not spared.

However, the regression of the series in level implicitly supposes the stationarity of the series. It is on this assumption that the validity of the classic tests is based (Student test, Fisher test). However, there are different tests to verify the validity of the stationarity assumption. Once this assumption is violated, the cointegration and causality approach are potential alternatives.

### *i. Stationarity tests or unit root tests*

The stationarity of a time series refers to a principle of temporal invariance of these moments of order. This temporal invariance of moments of order, qualified as strong stationarity is restricted to a notion of weak stationarity reflecting moments of order inferior or equal to two. Applied econometrics is based on weak stationarity notion.

The identification and characterization of the stationarity of a series can be done using several tests. The most used are those developed by Dickey and Fuller (1971, 1989). There are others less used than those of Dickey and Fuller. These are mainly the tests of Banerjee and al (1993), Darne and Terraza (2002), Phillips and Perron (1988) and Kwiatkowski Phillips, Scmidt and Shin (1992). Each of these tests has advantages and disadvantages. Dickey Fuller's model corrects autocorrelation, while Philips and Perron consider heteroskedasticity. The KPSS test is based on a decomposition of the series into a deterministic part and a random part. Unlike the others, the latter's null hypothesis is stationarity[9].

### *ii. The cointegration approach*

This approach introduced by Granger (1981) and Engle and Granger (1987) is based on the development of the notion of integration developed by the latter. Indeed, when one wishes to model the relation between variables not having the same orders of integration, one resorts to models applying the cointegration

[9] For more information on these tests, a large documentation exists.

approach because the regression on these series, not all stationary leads to problems of spurious regression. From an economic point of view, cointegration between two series refers to the existence of a stable relationship between both series even if it can experience some corrected short-term fluctuations.

The econometric literature offers several methodologies for analyzing the cointegration between two series. The most used methods are the two-step method of Engle and Granger (1987), the multivariate approach of Johansen (1988) and Johansen and Juselius (1990) and the bounds tests approach to cointegration of Pesaran and al (2001).

### *1. Engle and Granger approach (1987)*

The two-step approach of Engle and Granger (1987) is based on the representation of an MCE model. They showed that two cointegrated series could still be represented as an error correction model:

$$\Delta P_{2t} = \pi_{01} + \delta_1\left(P_{2t-1} - (\mu_1 + \alpha_1 P_{1t-1})\right) + \sum_{j=1}^{p-1} \gamma_{1ij} \Delta P_{it-j} + \sum_{i=1}^{q} \delta_{1ij} \Delta P_{1t-j} + \varepsilon_{1t} \quad (R1)$$

$$\Delta P_{1t} = \pi_{02} + \delta_2\left(P_{1t-1} - (\mu_2 + \alpha_2 P_{2t-1})\right) + \sum_{j=1}^{p-1} \gamma_{2ij} \Delta P_{1t-j} + \sum_{i=1}^{q} \delta_{2ij} \Delta P_{2t-j} + \varepsilon_{2t} \quad (R2)$$

This approach consists in estimating in the first step the error term $\varepsilon_{1t-1} = P_{2t-1} - (\mu_1 + \alpha_1 P_{1t-1})$ and then in the second step, estimating the relation ( R1) considering $\widehat{\varepsilon_{1t-1}}$ in place of $P_{2t-1} - (\mu_1 + \alpha_1 P_{1t-1})$ and ensure that $\varepsilon_{1t}$ is stationary.

However, it is important to ensure that:

- Both variables are I (1).
- The restoring force towards equilibrium $\delta_1$ is statistically different from zero and negative; otherwise, the MCE specification no longer holds.

However, this method has some limitations:

- The estimation of the long-term dynamics does not consider the information contained in the short-term dynamics.
- It is only applicable in the case of a single cointegration relationship.

### *2. Johansen's approach*

Johansen (1988) and Johansen and Juselius (1990) have proposed a multivariate approach that makes it possible to overcome the restrictive framework of the model of Engel and Granger (1987). The advantage of this approach is that it makes it possible to determine the number of cointegration relationships between several markets without having to determine a reference market with which the others are assumed to be linked. Thus, this approach assumes that the integration order of all the variables is equal to 1.

This method is based on the use of a VAR model to determine the optimal lag. Var(p) model is represented below.

$$P_t = \Pi_1 P_{t-1} + \Pi_2 P_{t-2} + \cdots + \Pi_p P_{t-p} + \mu + \varphi D_t + \varepsilon_t$$

$$\Pi = I - \Pi_1 - \Pi_2 - \cdots - \Pi_p \tag{9}$$

$$\Gamma_i = I - \Pi_1 - \Pi_2 - \cdots - \Pi_i,\ i=1 \ldots .\ p-1$$

If the rank of Π is zero, then there is no cointegration relation. A VAR with a difference of the variables could be estimated.

If the rank of Π is equal to the number of variables k, all the variables are stationary. It is therefore advisable to make a VAR (p) in level.

If 0 <rank (Π) = r <k, then two matrices α and β of rank r belonging to M (k, r) such that Π =αβ and $\beta' P_t$ is a stationary process.

By applying the Granger representation theorem that stipule that any cointegrated system has an ECM representation. Which means:

$$\Delta P_t = \alpha e_{t-1} + \Gamma_1 \Delta P_{t-1} + \Gamma_2 \Delta P_{t-2} + \cdots + \Gamma_{p-1} \Delta P_{t-p+1} + \mu + \varphi D_t + \varepsilon_t$$

$$e_{t-1} = \beta P_{t-1} \tag{10}$$

Johansen (1988) was able to demonstrate using a two-step procedure a method for estimating the number of cointegration relationships and the parameters of the matrix Π.

The first consists in regressing $\Delta P_t$ on its lags ($\Delta P_{t-i}, i = 1 \ldots p$) and the second consists in regressing $P_{t-1}$ on the same lags of ($\Delta P_{t-i}, i = 1 \ldots p$).

$$\Delta P_t = A_1 \Delta P_{t-1} + A_2 \Delta P_{t-2} + \cdots + A_p \Delta P_{t-p} + R_{0t}$$

$$P_{t-1} = A'_1 \Delta P_{t-1} + A'_2 \Delta P_{t-2} + \cdots + A_p \Delta P_{t-p} + R_{1t}$$

$$R_{0t} - \alpha\beta' R_{1t} = \epsilon_t \tag{11}$$

$$S_{ij} = \frac{R_i R_j}{T}$$

$$S = \begin{pmatrix} S_{11} & S_{10} \\ S_{01} & S_{00} \end{pmatrix}$$

The idea behind this two-step procedure is that it makes it possible to determine the canonical correlation matrix (S) between $\Delta P_t$ and $P_{t-1}$ adjusted for the lags of $\Delta P_t$ and the trend or a deterministic part in case these exist. However, the nonzero number of eigenvalues of the matrix ${S_{11}}^{-1} * S_{10} * {S_{00}}^{-1} * S_{01}$ allows to identify the number of cointegration relationship. These eigenvalues are the squares of the canonical correlations between the canonical variables $R_1$ and $R_0$.

Two tests based on eigenvalues have been developed by Johansen (1988) and Johansen and Juselius (1990).

- Trace test:

We suppose that there is a decreasing order of the estimated eigenvalues ($\lambda_1 > \lambda_2 > \cdots > \lambda_r$). Johansen (1988) shows that the log likelihood under the assumption of a cointegration line is equal to:

$$LR(r) = C - T \sum_{i=r+1}^{k} log(1 - \lambda_i) \tag{12}$$

Under H0: $rang(\Pi) = r_0$ VS H1 $rang(\Pi) = r_1 > r_0$

Under H0: $LR(r) = -T \sum_{i=\boldsymbol{r_0}+1}^{k} log(1 - \lambda_i)$

The critical values for this statistic have been tabulated by Johansen (1988).

- Maximum eigenvalue test

Johansen and Juselius (1990) suggested using the maximum eigenvalue test based on the following statistic test:

$$\lambda_{max} = -Tlog\left(1 - \lambda_{r_0+1}\right) \tag{13}$$

Critical values have been tabulated by Johansen and Juselius (1990) according to different specifications (deterministic, trend).

It should be remembered that the trace test is more robust than the Skewness and Kurtosis maximum eigenvalue test (if the residues are not normal), (Cheung and Lai (1993) and Gonzalo (1994)).

- Identification of α and β

One of the most complex parts of Johansen's approach is the estimation of the parameters α and β. This complexity is due to the problem of identifying the parameters α and β, which each contain k*r unknown parameters. Indeed, in the matrix αβ=Π, we can only identify $2kr-r^2$ parameters. Hence the need to place additional restrictions $r^2$ to ensure the complete identification of α and β. This restriction often poses the problem of economic interpretation if it was not considered a priori. In the case where there is only one cointegration relation, it is possible to estimate the parameters α and β.

However, if we have more than one cointegration relationship, it is necessary to use economic theory to impose restrictions allowing to have cointegration relationships in phase with economic theory.

### 3. Pesaran and al approach

Likewise, Johansen's approach, Pesaran and Shin (1997), Pesaran, Shin, and Smith (2001) developed the ARDL approach for analyzing cointegration. This approach, called the bounds tests approach or the approach of Pesaran and al, has the particularity to analyze cointegration when the integration order of series is inferior or equal to 1.

This new approach is based on the ARDL model in the form of an ECM described below:

$$\Delta P_{2t} = \pi_0 + \pi_1 P_{it-1} + \pi_2 P_{ct-1} + \sum_{j=1}^{p-1} \gamma_{2j} \Delta P_{2t-j} + \sum_{i=0}^{q} \delta_{1j} \Delta P_{1t-j} + \varepsilon_t \, (1) \quad \textit{(14)}$$

The elasticity of price transmission $\boldsymbol{\varepsilon} = \frac{\boldsymbol{\pi_2}}{\boldsymbol{\pi_1}}$ is given by the relation below:

$$\varepsilon = \frac{\pi_2}{\pi_1} = \frac{\sum_{j=0}^{q} \delta_{1j}}{1 - \sum_{j=1}^{p} \gamma_{2j}} \quad \textit{(15)}$$

The null hypothesis of non-cointegration between both variables is given by:

$$H_0^{\pi_1}: \pi_1 = 0, \; H_0^{\pi_2}: \pi_2 = 0 \quad \textit{(16)}$$

The test procedure consists of:

- Compute the test statistic (Fisher statistic) under the null hypothesis
- Compare the Fisher statistic with the two critical values at the limits tabulated by Pesaran and al. (2001). The lower bound assumes that all regressors are I (0), while the upper bound assumes that all regressors are I (1).

If F-stat> upper bound, then cointegration exists.

If F-stat <lower bound, cointegration is rejected.

If F-stat is between both bounds, look for other alternatives.

### iii. The causality approach

The cointegration between two variables already gives a causal link at least one of the directions. However, the approach of causality does not require a cointegration assumption and makes it possible to identify the causal links between variables and to limit the number of variables and relations in multivariate regressions. Indeed, in the context of markets integration, it is not always obvious the nature of the relationship between markets.

Hence the need to carry out tests. Two major conceptual approaches have been developed by Granger (1969) and by Sims (1980). Granger's (1969) approach is based on the ability of past values one of both series to improve the forecasting error of the other. About Sims (1980), he focuses on the ability of innovations in one of the series to help improve the forecasting error of the other.

In this technical note, the causality tests of Granger and Toda Yamamoto are developed. Another causality test like that developed by HSIAO (1981) exists, but not presented in this technical note.

### *1. Granger's causality test*

The Granger's causality is a statistical concept of causality based on the following definition. A $X_t$ serie causes a $Y_t$ serie if $X_t$ and its lags lead to improved prediction of $Y_t$ based solely on the past of $Y_t$. This test is based on the nullity test of the coefficients associated with the variables ($X_{t-i}$, 0 <= i <= p). It is based on the model defined below:

$$\begin{cases} Y_t = \alpha_1^0 + \sum_{i=1}^{p} \alpha_1^i Y_{t-1} + \sum_{j=1}^{q} \beta_1^j X_{t-1} + \varepsilon_t \\ X_t = \alpha_2^0 + \sum_{i=1}^{p} \alpha_2^i Y_{t-1} + \sum_{j=1}^{q} \beta_2^j X_{t-1} + u_t \end{cases} \tag{17}$$

H0: $X_t$ do not cause $Y_t$: $\beta_1^1 = \beta_1^2 = \cdots = \beta_1^p = 0$

H0: $Y_t$ do not cause $X_t$: $\alpha_2^1 = \alpha_2^2 = \cdots = \alpha_2^q = 0$

Under the hypothesis of stationarity of the variables, a Fisher test resulting from the estimation of a VAR model makes it possible to decide on the causality or not of the variables considered.

### *2. Toda and Yamamoto's causality test*

Several criticisms have been made of the use of Granger’s causality test. Among these, the supposed stationarity of the variables is the most frequent. Johansen and Juselius (1990), Philips and Toda (1993) have tried to improve Granger's test. Thus, Toda and Yamamoto (1995) developed a non-causality test based on the modification of the VAR model (p) and eliminates the restrictive analysis framework based only on integrated variables of the same order. For these authors, economists do not care much about the theoretical restrictions of stationarity and cointegration.

The estimate of this modified VAR consists of:

- Determine the integration order of all the variables and the maximum integration order (dmax).
- Estimate the VAR (p); which amounts to estimating the optimal $p^*$ by applying the AIC or BIC criteria.
- Estimate a VAR (p + dmax) defined as follows:

$$\begin{cases} Y_t = \alpha_1^0 + \sum_{i=1}^{p^*} \alpha_1^i Y_{t-1} + \sum_{i=p^*+1}^{p^*+dmax} \alpha_1^i Y_{t-1} + \sum_{j=1}^{p^*} \beta_1^j X_{t-1} + \sum_{j=p^*+1}^{p^*+dmax} \beta_1^j X_{t-1} + \varepsilon_t \\ X_t = \alpha_2^0 + \sum_{i=1}^{p^*} \alpha_2^i Y_{t-1} + \sum_{i=p^*+1}^{p^*+dmax} \alpha_2^i Y_{t-1} + \sum_{j=1}^{p^*} \beta_2^j X_{t-1} + \sum_{j=p^*+1}^{p^*+dmax} \beta_2^j X_{t-1} + u_t \end{cases} \quad (18)$$

Under H0: $\beta_1^i = 0, i = 1,2, \dots, p^*$ , $X_t$ do not cause $Y_t$.

The modified Wald test statistic is given by:

$$S = T * (\widehat{\beta_1}' * R' * (R * \Sigma_v * R')^{-1} * R * \widehat{\beta_1}) \sim > \varkappa_2^2(p^* + dmax) \quad (19)$$

Where $\beta = (\beta_1^1, \beta_1^2, \dots, \beta_1^p)$; $\Sigma_v$: Covariance variance matrix of (ε, u);

R: Matrix identifying the restrictions under the null hypothesis.

### *c. Non-linear econometric models*

Models postulating the hypothesis of the linear model stability over time have been often criticized. Indeed, for reasons of structural change, certain parameters over time change continuously or discreetly. This questioning of the validity of linear econometric methods pushed forward the analysis of threshold models (TAR, TVECM, ...).

These models are based on asymmetric shock transmission assumption, the extent of which depends on the nature of the shock. This implies that in the event of a price shock leading to a deviation from the equilibrium exceeding a certain critical threshold, economic agents act to bring the system back to equilibrium (Badolo, 2012). Indeed, the soaring prices of agricultural products on international markets during the 2006-2008 period did not have the same effect in all developing countries. This situation reflects the existence of actors (States, commercial intermediaries, etc.) and of mechanisms governing the transmission of prices. As a result, in the event of imperfect competition or policy of support for price stability, price increases are not even transmitted in the same way as decreases.

The TAR, MTAR and TVECM models provide an asymmetric fit verification framework.

#### *i. TAR and MTAR models*

The idea of estimating non-linear autoregressive models is introduced by Tong (1978, 1980, 1983, 1990). These models can be used to test the hypothesis of asymmetric price shock transmission. They rely on the validity of the linear autoregressive model and the symmetric price shock transmission hypothesis to test the asymmetric transmission hypothesis.

In this technical note, the method of Enders and Granger (1998) based on an autoregressive threshold model (TAR) is adopted to test the shock asymmetry hypothesis. Others threshold cointegration tests are used to test the shock asymmetry hypothesis. These are particularly the tests of Tsay (1989), Hansen and Seo (2002), and Seo (2006).

Considering: $P_{2t} = \mu_0 + \alpha_1 P_{1t} + U_t$, the relation linking the two markets supposing that $P_1$ is the price of the central market and $P_2$ the price of the local market.

Enders and Granger (1998) proposed that $U_t$is an autoregressive process defined as follows:

$$\Delta U_t = \rho_1 I_t U_{t-1} + \rho_2 (1 - I_t) U_{t-1} \tag{20}$$

With $I_t$ indicator function which can take two forms depending on the assumption made on the threshold dynamics. If the adjustment dynamics are more affected by residuals change in level, it is preferable to use the SETAR model which is often called the TAR model. However, if the adjustment dynamics are guided by the amplitude change of the residual variations, the MTAR model is more suitable for modeling asymmetric adjustment.

In the case of a SETAR model, the indicator function $I_t$ is defined as follows:

$$I_t = \begin{cases} 1 \; si \; U_{t-1} \geq \tau \\ 0 \; si \; U_{t-1} < \tau \end{cases} \tag{21}$$

About the MTAR model, the indicator function $I_t$ is described below:

$$I_t = \begin{cases} 1 \; si \; \Delta U_{t-1} \geq \tau \\ 0 \; si \; \Delta U_{t-1} < \tau \end{cases} \tag{22}$$

The threshold τ can be estimated with Tsay (1989), Chan (1993), and Hansen (1993) methods. Chan's (1993) method, using grid search, is widely used. This consists of excluding 15% of the highest and 15% of the lowest residual values. The optimal threshold, value among the 70% of the values of the residuals remaining, corresponds to that which minimizes the sum of the squared residuals.

The asymmetric transmission hypothesis test requires that the coefficients $\rho_1$ *and* $\rho_2$ be negative and different. For this, the test of Enders and Siklos (2001) based on the T-max statistics (based on H0: max $(\rho_1, \rho_2)$=0 vs max $(\rho_1, \rho_2)$<0) allows to test the negativity of the coefficients $\rho_1$ and $\rho_2$. The Fisher test makes it possible to test the difference of these two coefficients.

### *ii. ECM-TAR, ECM-MTAR and TVECM models*

TAR and MTAR models do not analyze the short-term price transmission dynamics. However, the threshold error correction models (ECM-TAR, ECM-MTAR and TVECM, etc.) offer the possibility of testing the dynamics of asymmetric adjustment and analyze short-term price transmission dynamics. We are focusing on the TVECM model because the ECM-TAR and ECM-MTAR models are the error correction versions of the TAR and MTAR models.

Considering the TVECM model below:

$$P_t = (P_{1t}, P_{2t}), \beta = (1, -\beta),\ U_{t-1}(\beta) = \beta' P_t$$

$$X_{t-1}(\beta) = (1, U_{t-1}(\beta), \Delta P_{t-1}, \Delta P_{t-2}, \dots, \Delta P_{t-p})$$

$$\rho_1 = (\rho_{11}, \rho_{12}), \rho_2 = (\rho_{21}, \rho_{22})$$

$$\alpha_{1i} = (\alpha_{11i}, \alpha_{12i}),\ \alpha_{2i} = (\alpha_{21i}, \alpha_{22i})$$

$$\Delta P_t = \left(\rho_1 U_{t-1}(\beta) + \sum_{i=1}^{p} \alpha_{2i}^{I_t} \Delta P_{2t-i} + \sum_{i=0}^{p} \alpha_{1i}^{I_t} \Delta P_{1t-i}\right) * I_t + \left(\rho_2 U_{t-1}(\beta) + \sum_{i=1}^{p} \alpha_{2i}^{1-I_t} \Delta P_{2t-i} + \sum_{i=0}^{p} \alpha_{1i}^{1-I_t} \Delta P_{1t-i}\right) * (1 - I_t) + \varepsilon_t \tag{23}$$

Hansen and Seo (2002) developed an estimation method based on the joint search for β and τ based on the maximum likelihood method. The non-linearity test ($\rho_1 = \rho_2$) proposed by these authors is based on the Lagrange multiplier test (LM test) or score test.

However, Seo (2006) questioned the two-step procedure of Hansen and Seo (2002) because the tests may suffer from power loss when the alternative is threshold cointegration. He has developed a non-linearity test, named BAND_TVECM, in which the cointegration vectors are pre-specified.

## III. Data and Results

### *a. Data*

Data used for the application of the theoretical models presented come from the FAO website[10]. This is the monthly prices of a kilogram of imported rice from Thailand and imported rice into Senegal between January 2007 and December 2019. Senegal imported rice price was collected from the Dakar market and Thies market. The use of these data aims to analyze the integration between the rice markets of both countries (Senegal and Thailand), and both regions (Dakar and Thies), but also to measure the integration degree of both markets, as well as the price transmission mechanisms.

However, to ensure consistency in all price data, they were expressed in CFA and deflated by the food price index. However, it is necessary to correct the imperfections, particularly the outliers and the missing values, and to make sure as much as possible the explanation of the links between the markets considered. As part

[10] https://fpma.apps.fao.org/giews/food-prices/tool/public/#/dataset/domestic

of econometric analyzes, the price data was transformed into a logarithm so that the effects could be explained as elasticities.

b. *Results*

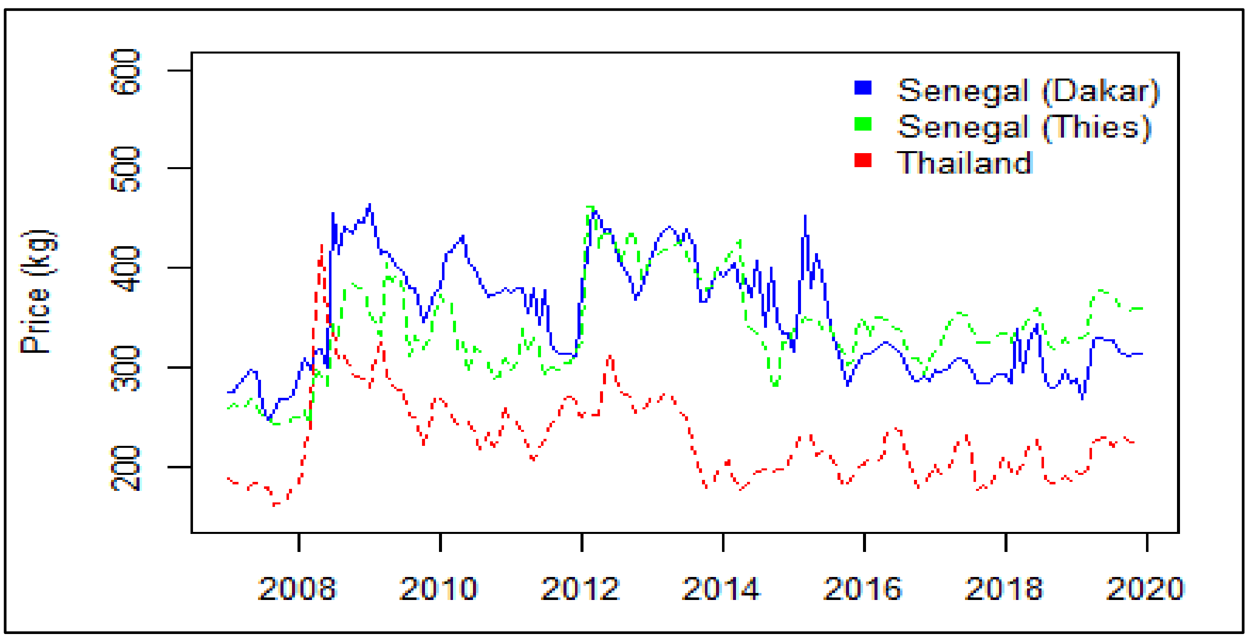
*i. Descriptive analysis*

*1. Graphical analysis*

It is always important to make a brief graphical representation of the data to gain insight into the trend and the nature of the existing relationships. However, this preliminary, although useful, can reveal irrelevant and even almost nonexistent relationships.

Figure 1 shows the monthly prices of a kilogram of rice evolution from Dakar, Thies and Thailand from January 2007 to December 2019. The observation that emerges is the tendency of series to trend together over time., but in the same direction. There is a presumption of cointegration between these three variables. The analysis of these relations between these three prices need to be developed further with the application of the econometric models presented above. However, the focus will be on the analysis of the rice markets in Dakar and Thailand and the rice markets in Dakar and Thies.

*Figure 1 : Price trends of rice from Senegal (Dakar and Thies) and Thailand*




Source: Authors

*2. Numerical analysis*

Beyond the graphic description of the relationship between markets prices (Dakar and Thailand, Dakar and Thies), it is possible to quantify the relationship with the correlation of Pearson, Spearman, and Kendall.

These correlations, presented in Table 1, show that the Dakar and Thailand markets and the Dakar and Thiès markets are integrated if the Pearson, Spearman, and Kendall correlation coefficients are considered valid, as well as the significance of the three correlation coefficients. Indeed, a correlation greater than 0.5 is considered quite high.

*Table 1 : Pearson, Spearman, and Kendall Correlation*

| **Correlation** | **Dakar et Thaïlande** | | **Dakar et Thiès** | |
|---|---|---|---|---|
| | **Corrélation** | **P-value** | **Corrélation** | **P-value** |
| Pearson | 0.57 | 6.93E-15 | 0.65 | 6.34E-20 |
| Spearman | 0.68 | 2.33 E-23 | 0.62 | 4.01E-18 |
| Kendall | 0.52 | 9.21E-22 | 0.45 | 6.14E-17 |

Source: Authors

Before proceeding with the interpretation of the Pearson coefficient, it is often necessary to diagnose the hypotheses that ensure the validity of this analysis tool. For that, it is possible to represent boxplot and the Q-Q plots to have a graphic vision on probably extreme values and the nature of price distributions. Besides, the tests of extreme values (Grubbs test, etc.) and normality (Jarque-Bera, Shapiro-Wilk, etc.) allow us to check such hypotheses.

These imperfections can compromise Pearson's correlation test. Faced with these, non-parametric tests (Spearman and Kendall) are advised even if these require the hypothesis of monotony. In addition, the transformation of continuous data can lead to the distortion of relationships.

### *ii. Econometric results of linear models*

#### *1. Stationarity or unit root tests*

Unit root tests are the starting points of most of time series analyses. The basic assumption on which econometric tests are based is stationarity, particularly the Pearson test. If this is not verified, it can lead to a strong correlation without there being a relationship between both series (fallacious regression problem). For example, two series having common trends may have a strong correlation, while the only reason explaining this relationship is the trend. These are the kind of problems that are the subject of the stationarity diagnosis.

Stationarity tests applied to price series from Senegal (Dakar and Thies) and Thailand show non-stationarity in level and stationarity in difference to the Dakar and Thies price series from Senegal (ADF, Phillips Perron and KPSS). As for the price series from Thailand, we found level stationarity (ADF test) at the 5% threshold and level non-stationarity (Phillips Perron and KPSS) and difference stationarity (Phillips Perron and KPSS).

*Table 2 : Unit root tests*

| | ADF (p-val) | | PP (p-val) | | KPSS (p-val) | |
|---|---|---|---|---|---|---|
| | **level** | **Difference** | **level** | **Difference** | **level** | **Difference** |
| Senegal (Dakar) | 0.25 | 0.01 | 0.09 | 0.01 | 0.01 | 0.1 |
| Senegal (Thiès) | 0.23 | 0.01 | 0.11 | 0.01 | 0.03 | 0.1 |
| Thailand | 0.04 | 0.01 | 0.07 | 0.01 | 0.01 | 0.1 |

Source: Authors

We can retain that the Dakar and Thiès price series of Senegal are integrated of order (1) and the price series of Thailand has an order of integration less than or equal to 1. For the purposes of applying this technical note, we will assume that the price series of Thailand has an order of integration equal to 1 (majority tests) in the case of the Granger and Johansen tests and the estimation of the VECM models.

### 2. Cointegration tests

The non-stationarity of the rice price series of both countries finds its full meaning in the cointegration analysis. The latter, developed within the context of the econometrics of non-stationary series, makes it possible to study the relationship between the prices of rice of both countries, particularly the integration between these markets (Dakar and Thailand, Dakar and Thies). Integration order of series supposed to be equal or inferior to 1, make it possible to apply the cointegration tests and estimate the theoretical models presented in this technical note. These tests allow on the one hand to validate or not the existence of an integration relationship and on the other hand to assess with the help of an estimate the degree of integration relationship between both markets.

- Engle and Granger's approach (1987)

The dichotomy of Engle and Granger's (1987) approach means that there is no direct link between the cointegration test and the estimation of the short-term relationship. Table 3 presents the results of unit root test-based the Phillips-Perron, Pantula, Gonzales-Farias and Fuller tests. We can accept the hypothesis of the existence of a cointegrating relationship between the Senegal and Thailand markets, as well as the Dakar and Thies markets. However, care must be taken to test the hypotheses (autocorrelation, normality) for estimating the long-term relationship, as well as to integrate the omitted variables.

*Table 3 : Engle and Granger cointegration test*

| **Unit Root Tests of Residuals** | **Dakar and Thaïlande** | **Dakar and Thiès** |
|---|---|---|
| | **P-value** | **P-value** |
| Phillips-Perron (PP) | 0.01 | 0.05 |
| Pantula, Gonzales-Farias and Fuller (PGFF) | 0.03 | 0.04 |

Source: Authors

- Johansen's approach

Engle and Granger's approach is limited to an estimation of a long-term relationship and the non-stationarity test to decide on integration between two markets. Johansen's approach thus offers a more general framework for analysis, particularly in the case of several markets, and combines an analysis of the long-term and short-term relationship. Table 4 presents the results of the Johansen test and the estimation of the VECM model considering the case of rice markets in Senegal and Thailand and the case of rice markets in the Dakar and Thies region. The Johansen trace test shows that there is a price cointegration relationship in both cases. This confirms that there is an integration relationship between the rice markets of Senegal (Dakar) and Thailand and the rice markets of Dakar and Thies. In addition, the adjustment coefficients for the rice markets of Senegal and Thailand and the rice markets of Dakar and Thiès, which are negative and strictly less than 1, are -17 and -21, respectively. These results reflect the validity of long-term relationships, and long-term coefficients almost equal to 1 could imply perfect price transmission and strong integration between these markets.

*Table 4 : Johansen cointegration test*

| | **Senegal (Dakar) et Thaïlande** | | | | **Dakar et Thies** | | | |
|---|---|---|---|---|---|---|---|---|
| **Johansen Test Trace** | **Test** | **10pct** | **5pct** | **1pct** | **Test** | **10pct** | **5pct** | **1pct** |
| r <= 1 | 10.24 | 10.49 | 12.25 | 16.26 | 7.11 | 10.49 | 12.25 | 16.26 |
| r = 0 | 41.89 | 22.76 | 25.32 | 30.45 | 29.74 | 22.76 | 25.32 | 30.45 |
| **Sort run** | **Estim** | **Std. Err** | **Pr(>\|t\|)** | | **Estim** | **Std. Err** | **Pr(>\|t\|)** | |
| ect1 | **-0.17** | 0.03 | 0.00*** | | **-0.21** | 0.06 | 0.00** | |
| dLog_Price_**DK**.1 | -0.37 | 0.08 | 0.00*** | | -0.39 | 0.09 | 0.00** | |
| dLog_Price_**TL**.1 | -0.07 | 0.08 | 0.35 | | | | | |
| dLog_Price_**THS**.1 | | | | | 0.20 | 0.09 | 0.03 * | |
| Constant | 0.06 | 0.01 | 0.00*** | | -0.04 | 0.01 | 0.00** | |
| **Long run** | **ect1** | | | | **ect1** | | | |
| Log_Price_**DK**.2 | 1.00 | | | | 1.00 | | | |
| Log_Price_**TL**.2 | **-1.01** | | | | | | | |
| Log_Price_**THS**.2 | | | | | **-1.07** | | | |
| Trend | -0.00 | | | | 0.002 | | | |

Signif. codes: *** p<0.00, ** p<0.01, *p<0.05
dLog_Price_DK.1: first difference in the logarithm of the Dakar rice price delayed by one period
dLog_Price_TL.1: first difference of the logarithm of the Thai rice price delayed by one period
dLog_Price_THS.1: first difference of the logarithm of the Thiès rice price delayed by one period
Log_Price_DK .2: logarithm of Dakar rice price delayed by two periods
Log_Price_TL.2: logarithm of Thai rice price delayed by two periods
Log_Price_THS.2 : logarithm of Thiès rice price delayed by two periods
Source: Authors

- Pesaran and al (2001) approach

Johansen's approach requires that the series be integrated of order 1. Pesaran et al (2001) develop a framework for analyzing the cointegration of series that are not all integrated of the same order and of order of integration less than or equal to 1. Price series that are integrated of order less than or equal to 1 join the requirements of the Pesaran et al (2001) test. In the same logic as the cointegration test of Engle and Granger and Johansen, the test of Pesaran et al (2001) presented in Table 5 also shows that the hypothesis of market integration cannot be rejected (the F-statistic is higher than the upper bound). In addition to this, the adjustment coefficients for the rice markets of Senegal (Dakar) and Thailand and the rice markets of Dakar and Thiès, which are negative and strictly less than 1, are -0.20 and -0.29, respectively. These results stipulate on the one hand that 20% of the positive or negative deviations between the Senegalese and Thai markets are absorbed within one month. On the other hand, 29% of the positive or negative deviations between the Dakar rice market and the Thies rice market are eliminated over the same period. This result implies that adjustment is much faster under horizontal integration (Dakar and Thiès) than under vertical integration (Thailand and Senegal).

As for the long-term relationships of the rice markets of Senegal (Dakar) and Thailand and the rice markets of Dakar and Thiès, they all have a long-term coefficient that is not significantly different from 1. This result reflects perfect price transmission and strong integration of these markets. The rejection of the segmentation of these markets can be inferred by referring to the coefficients of the short-term relationships.

*Table 5 : Pesaran and al cointegration test*

| | **Senegal (Dakar) et Thaïlande** | | **Dakar et Thiès** | |
|---|---|---|---|---|
| **Pesaran et al cointgartion test** | **---I (0) ---** | **---I (1) ---** | **---I (0) ---** | **---I (1) ---** |
| 10% critical value | 5.59 | 6.26 | 5.59 | 6.26 |
| 5% critical value | 6.56 | 7.3 | 6.56 | 7.3 |
| 1% critical value | 8.74 | 9.63 | 8.74 | 9.63 |
| F-statistic = 11.01 | 10.81 | | 10.55 | |
| **Sort-run relation:** | **Estimate** | **Pr(>\|t\|)** | | |
| (Intercept) | 0.29 | 0.00 *** | 0,14 | 0.00 *** |
| ec.1 | **-0.20** | 0.00 *** | **-0,29** | 0.00 *** |
| dLog_Price_TL.t | 0.26 | 0.00 ** | | |
| dLog_Price_TL.1 | -0.18 | 0.03 * | | |
| dLog_Price_DK.1 | -0.16 | 0.04 * | -0,19 | 0.02 * |
| dLog_Price_THS.t | | | 0,46 | 0.00 *** |
| dLog_Price_THS.1 | | | 0,09 | 0.34 |
| trend.t | 0.00 | 0.52 | 0 | 0.00 *** |
| **Long-run relation** | **Estimate** | | | |
| Log_Price_DK.1 | -0.20 | 0.00 *** | -0.29 | 0.00 *** |
| Log_Price_TL.1 | 0.16 | 0.00 ** | | |
| Log_Price_THS.1 | | | 0.27 | 0.00 ** |
| **Long-run coefficients** | **Estimate** | | **Estimate** | |
| beta | 0.81 | | 0.95 | |
| P-value (Wald test): beta=1? | 0.88 | | 0.96 | |

signif codes : *** p<0.00, ** p<0.01, *p<0.05
dLog_Price_DK.1: first difference of the logarithm of the Dakar rice price delayed by one period
dLog_Price_TL.1: first difference of the logarithm of the Thai rice price delayed by one period
dLog_Price_THS.1 : first difference of the logarithm of the Thiès rice price delayed by one period
Log_Price_DK .1: logarithm of Dakar rice price delayed by one period
Log_Price_TL.1: logarithm of the price of rice from Thailand delayed by one period
Log_Price_THS.1 : logarithm of Thiès rice price delayed by one period
Source: Authors

These three approaches, although different in theory, have found the same result, which is the existence of a market cointegration relationship. However, differences were noted on the estimation of the adjustment and the long-term coefficient. The adjustment coefficient reflects the speed of adjustment, which transformed into its inverse expresses the adjustment duration of the two markets in the event of positive or negative deviations. Following Timmer's (1987) approach, the long-term coefficient could be interpreted as an index of market competitiveness.

### *3. Causality tests*

The existence of a cointegrating relationship is not always verified and one is always interested in the causal relationship between two series that are not integrated. More generally, Granger's causality test and Toda Yamamoto test do not require any hypothesis on market cointegration. However, cointegration implies causality in at least one direction. This means that even without a causality test, it can be said that the price of rice in Thailand is a cause of the price in Senegal, or vice versa. Senegal being a small country (price taker) importer, we logically expect to have the Thailand price causes the price rice from Senegal and not the other way around. Referring to the Granger and Toda Yamamoto causality tests, respectively presented in Tables 6 and 7, show that the price of rice from Thailand causes the price of rice from Senegal and the price of rice from Senegal does not cause the price of rice from Thailand.

As for causality between the price of rice from Dakar and the price of rice from Thies, the Granger test does not allow for a two-way causality to be concluded. On the other hand, the Toda Yamamoto test shows that the price of rice from Dakar causes the price of rice from Thies and vice versa. This result, which is much more robust than the simple Granger test in our context, may reflect the fact that these two regions respond in the same way to the transmission of shocks from exporting countries and share the same networks of commercial intermediaries, as well as the same mechanisms governing price.

*Table 6: Granger causality test*

| Cas | H0 | P-value |
|---|---|---|
| **Senegal et Thaïlande** | Senegal's rice price does not cause Thailand's price | 0.67 |
| | Thailand's rice price does not cause Senegal's price | 0.01 |
| **Dakar et Thiès** | The price of rice in Dakar does not cause the price of rice in Thies. | 0.31 |
| | The price of rice in Thies does not cause the price of rice in Dakar. | 0.03 |

Source: Authors

*Table 7: Toda Yamamoto causality test*

| Cas | H0 | P-value |
|---|---|---|
| **Sénégal et Thaïlande** | Senegal's rice price does not cause Thailand's price | 0.72 |
| | Thailand's rice price does not cause Senegal's price | 0.01 |
| **Dakar et Thiès** | The price of rice in Dakar does not cause the price of rice in Thies. | 0.03 |
| | The price of rice in Thies does not cause the price of rice in Dakar. | 7.7e-06 |

Source: Authors

### *iii. Econometric results of non-linear models*

It is important to understand that linear models can provide information on price transmission mechanisms, but their results could be biased when the assumption of linearity is not respected. As such, non-linear models provide a more consistent analytical framework to address non-linearity issues. They allow the analysis of the asymmetric transmission mechanism.

In the case of the TAR, MTAR, ECM-TAR and ECM-MTAR models, we have retained that the international price of rice from Thailand causes the price of rice imported from Senegal (already shown by the Granger and Toda-Yamamoto tests).

#### *1. TAR, MTAR*

The results of the TAR and MTAR model, presented in Table 8, provide a framework for asymmetric price adjustment analysis in the case of the rice markets of Senegal and Thailand and the case of the rice markets of Dakar and Thies. Table 8 presents the non-linearity tests, adjustment coefficients and thresholds for the two models.

For the case of the rice markets of Senegal and Thailand, the null hypothesis of symmetrical adjustment was not rejected by the TAR model (p- value=0.29), but only by the MTAR model (p-value=5.5e-07). Indeed, the two results are not contradictory. The TAR model is adapted for changes in level, while the MTAR model reflects the dynamics of adjustment guided by changes in the amplitude of the variations. Therefore, the MTAR model is the model retained to analyze asymmetric adjustment dynamics. The estimated adjustment coefficients $\rho_1$ *and* $\rho_2$ are respectively -0.55 and -0.05 (not significant). These results indicate that 55% of the positive deviations (i.e., a drop in the international price of Thailand rice corresponding to a positive value of the long-term margin) are absorbed within one month. On the other hand, for negative deviations (i.e., a negative value of the long-term margin corresponding to an increase in the international price), no adjustment is observed in the short-term dynamics. One of the main reasons put forward to explain this situation is the existence of distortions, resulting from authoritarian pricing by the government and subsidization of rice imports in the event of an increase. In 2008, the government to stabilize prices reacted by suspending the 10% customs duties (fiscal measures) on rice imports, supporting consumer prices by subsidizing rice imports to 35-41 Fcfa/kg and ensuring price control and fixing.

Analysis of the asymmetry of price transmission between the Dakar and Thiès rice markets using the TAR and MTAR models does not reveal asymmetric transmission of rice prices between these two regions. Nevertheless, these results show the need to use non-linear models in order to understand price transmission mechanisms and adjustment dynamics, particularly for the relations between the international and domestic markets.

*Table 8 : TAR and MTAR models*

| Models | Senegal and Thailand | | | | Dakar et Thiès | | | |
|---|---|---|---|---|---|---|---|---|
| | TAR | | MTAR | | TAR | | MTAR | |
| | Estim | P-val | Estim | P-val | Estim | P-val | Estim | P-val |
| $\rho_1$ | -0.14 | 0.02 * | -0.55 | 4.9e-10*** | -0.19 | 0.00 ** | -0.14 | 0.17 |
| $\rho_2$ | -0.24 | 0.00** | -0.05 | 0.35 | -0.04 | 0.49 | -0.11 | 0.03 * |
| H0: SH: $\rho_1 = \rho_2$ (P-v) | 0.29 | | 5.5e-07 *** | | 0.09 | | 0.77 | |
| Threshold | -0.1 | | 0.05 | | 0.08 | | 0.05 | |

Signif. codes : *** p<0.00, ** p<0.01, *p<0.05
SH: Symmetric Hypothesis
Source: Authors

### *2. ECM-TAR, ECM-MTAR*

It is always possible to go beyond the results given by the TAR and MTAR models by looking at threshold error correction models (ECM-TAR and ECM-MTAR). We can understand them as dynamics that complement the TAR and MTAR models to analyze short-term price dynamics.

The results of the ECM-TAR model, presented in Table 9, indicate that there is no asymmetrical fit, as found in the case of the TAR model. However, the results of the ECM-MTAR model confirm the assumption of asymmetric adjustment. The latter shows that the dynamics of price adjustment is not instantaneous. However, this result must be analyzed with caution because the existence of asymmetric adjustment should motivate the analysis of this short-term dynamic in two regimes.

These results reflect the importance of studying short-term dynamics. However, the threshold error correction models presented above must be interpreted with great caution because the short-term dynamics do not incorporate asymmetric adjustment. The TVECM model provides a more general framework for analyzing the results by regime while integrating the short-term dynamics.

*Table 9 : ECM-TAR and ECM-MTAR models*

| Modeles | ECM-TAR | ECM-MTAR |
|---|---|---|
| **dLog_Price_DK** | **Estimate** | **Estimate** |
| | | |
| H0: SH $\rho_1 = \rho_2$ | 0.1 | 0.00*** |
| | | |
| Threshold | -0.1 | 0.05 |
| | | |
| $\rho_1$ | | -0.58*** |
| $\rho_2$ | | -0.06 |
| | | |
| dLog_Price_TL.1 | | -0.03 |
| dLog_Price_DK.1 | | -0.02 |
| (Intercept) | | 0.01 |

Signif. codes: *** p<0.00, ** p<0.01, *p<0.05
dLog_Price_DK.1: first difference in the logarithm of the Dakar rice price delayed by one period.
dLog_Price_TL.1: first difference of the logarithm of the Thai rice price delayed by one period
SH: Symmetric Hypothesis
Source: Authors

### *3. TVECM*

This model offers a more general framework than that proposed by the TAR, MTAR, ECM- TAR and ECM-MTAR models. It allows the analysis of asymmetric transmission by focusing on the different types of existing regimes. However, this model requires the testing of some fundamental assumptions. For this, it is necessary to ensure that the causal relationship is bilateral. Therefore, we will limit ourselves to the case of the Dakar and Thiès rice prices. The latter presents a bilateral causal relationship between rice prices in the two regions (see Toda & Yamamoto test).

However, the interpretation of the results of the TVECM model requires that Hansen and Seo's (2002) test validates the hypothesis of asymmetric adjustment. The results in Table 10 indicate, based on the test of Hansen and Seo (2002), that there is no asymmetric adjustment to the price of rice in Dakar and Thiès. This result is consistent with the hypothesis of symmetric price transmission between these two regions (Dakar and Thiès) found with the previous models (TAR and MTAR).

*Table 10 : Results of TVECM model*

| Dakar et Thiès | | | | |
|---|---|---|---|---|
| Hansen et Seo (2002) test | H0 : | **P-value= 0.42** | | |
| **Résultats Économétriques** | | | | |
| | **ECT** | **dLog_Price_DK.1** | **dLog_Price_THS.1** | **Const** |
| **VECM : Linear Method** | | | | |
| dLog_Price_DK | **-0.22(0.07)*** ** | -0.16(0.08) * | -0.04(0.10) | -0.05(0.02)** |
| dLog_Price_THS | 0.10(0.03) | 0.06(0.08) | -0.07(0.09) | 0.02(0.01) |
| **Cointegrating vector** | (1, -1.07) | | | |
| **TVECM : No Linear Method** | | | | |
| **Regime 1-: Bdown, 37%** | | | | |
| dLog_Price_DK | -0.15(0.13) | -0.07(0.60) | 0.23(0.06) | -0.01(0.36) |
| dLog_Price_THS | -0.02(0.85) | 0.21(0.11) | -0.04(0.71) | -0.01(0.61) |
| **Regime 2 : Bup, 63%** | | | | |
| dLog_Price_DK | -0.54(0.00)*** | -0.17(0.10) | -0.075(0.63) | 0.09(0.00)*** |
| dLog_Price_THS | 0.06(0.63) | 0.03(0.77) | -0.20(0.15) | 0.00(0.10) |
| Seuil | **0.06** | | | |

Signif. codes : *** p<0.00, ** p<0.01, *p<0.05
dLog_Price_DK.1: first difference in the logarithm of the Dakar rice price delayed by one period.
dLog_Price_TL.1: first difference of the logarithm of the Thai rice price delayed by one period
dLog_Price_DK: first difference in the logarithm of the Dakar rice price
dLog_Price_TL: first difference of the logarithm of the Thai rice price
dLog_Price_THS: first difference of the logarithm of the Thiès rice price
Source: Authors

Admittedly, The TVECM model provides a framework for analyzing market integration in the presence of asymmetric price transmission, but both the TVECM and VECM models require that series be integrated of order 1, as well as the existence of causal relationships between the variables involved in the relationships. To this end, the development of the TARDL model would be a favorable framework for analyzing market integration, particularly in the case of price series with integration orders less than or equal to 1.

## IV. Conclusion

The analysis of market integration is a powerful tool for understanding the relationships between geographically distant markets, analyzing the impact of liberalization policies, as well as the identification of regions exposed to systematic shocks. To this end, the literature offers various tools for analyzing market integration.

However, choosing the right tool is not straightforward. It is guided by the data availability and the results of tests carried out, but also by the understanding of the formal and non-formal relationships existing between markets considered. For most studies, like this technical note, price data is often used.

This technical note, compared to other studies, has the particularity of presenting different tools while focusing on their applicability conditions, their strengths, and their weaknesses. These different tools can be classified into two approaches: the descriptive approach and the econometric approach.

The descriptive approach, considered to be the traditional approach, focuses on the analysis of correlation. It provides an important preliminary description of the relationships between the markets. Although the descriptive approach is necessary to get an overview of supposed relationships between markets, the econometric approach offers a more complete and rigorous analysis. The emergence of these methods is one of the main elements that have contributed to the development of tools to measure market integration. These methods can be classified into two categories: linear econometric methods and non-linear econometric methods. These both latter analyze the symmetric adjustment and asymmetric adjustment mechanisms, respectively. These methods are based on the use of the following elements: unit root tests, cointegration, causality, speed of adjustment, and symmetry of relations.

However, the econometric results within the framework of this technical note, as well as within the framework of other studies must be interpreted with caution because these methods are in full development and must be linked to qualitative information which can support their validities.

Moreover, it is difficult to verify a scientific hypothesis in isolation (Duhem-Quine's thesis), and particularly the hypothesis of market integration. The latter cannot free itself from auxiliary hypotheses such as the stationarity of transaction costs and market structure (Bonjean and Combes, 2010).

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