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Price volatility of food staples. The case of millet in Niger

Osama Ahmed¹ and Teresa Serra²

¹Centre de Recerca en Economia i Desenvolupament Agroalimentaris (CREDA)-

UPC-IRTA, Parc Mediterrani de la Tecnologia, Edifici ESAB,

C/ Esteve Terrades 8, 08860 Castelldefels, Spain.

Tel.: +34 935-521-209; fax: +34 935-521-121.

***E-mail address:* osama.ahmed.nasreldin@upc.edu**

²Centre de Recerca en Economia i Desenvolupament Agroalimentaris (CREDA)-

UPC-IRTA, Parc Mediterrani de la Tecnologia, Edifici ESAB,

C/ Esteve Terrades 8, 08860 Castelldefels, Spain.

Tel.: +34 935-521-209; fax: +34 935-521-121.

***E-mail address:* teresa.serra-devesa@upc.edu**



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Abstract

This article aims to examine dependence between producer and consumer prices for millet markets in Niger. Links between prices considered are assessed by cointegration analysis and statistical copula methods. Results indicate a positive link between producer and consumer prices, which is stronger the closer the markets are. Evidence of asymmetric price behavior is also found.

Key Words: food staple, asymmetric price transmission, statistical copula.

JEL CLASSIFICATION: C5, Q11, Q 12, Q 18

1. Introduction

While risk is not exclusive of agricultural economic activities, the agricultural sector typically faces a combination of risks that is rarely found in other enterprises. Two of the major risks affecting agriculture are climatic and natural risks that can influence agricultural yields, and market risks that may lead to important agricultural price fluctuations. Agricultural price behavior has changed after the recent 2007/08 and 2010/11 global food crises, leading to unprecedented increases in food prices that may exacerbate chronic food insecurity and poverty.

According to Food and Agriculture Organization of the United Nations (FAO, 2013), in 2010-2012, 868 million people (12.5% of the world population), most of them located in developing countries, were suffering from undernourishment. Prevalence of food inadequacy reached 19.1% of the global population, and 22.5% of the population in developing countries (FAO, 2013), being the result of widespread poverty. Around 20% of the world population lives below the poverty line (World Bank, 2010). The costs of food imports in developing countries increased from US\$185.5 million in 2006 to US\$343.1 million in 2008, an increase of 85% (Ifad, 2009), which has been partly due to an extreme rise in food prices.

Guaranteeing availability and access to food is vital in less developed country (LDC) economies, and can be enhanced in a number of different ways. Local food reserves, for example, have been promoted by different organizations and small producer federations with the objectives of increasing farm income and food security. Despite their potential to promote food security, there is an important failure rate of local food reserve initiatives in LDCs. Guaranteeing sustainability of these reserves requires profound knowledge of price behavior (Oxfam, 2012). More specifically, it is important to characterize the relationship between producer and consumer markets, which are indicative of the purchase and sale prices of food reserves. Lack of food price data in LDCs is the reason underlying the scarcity of studies on price behavior in these countries. This makes the contribution of the analysis proposed in this paper a very relevant one.

Price behavior of food staples is one of the most complex factors affecting food security. Further, since risk may affect food producers and consumers differently, it is also relevant to assess how price changes are transmitted along the food marketing chain, from producers to final food consumers. This paper will pay attention to study the price of food staples in Niger, one of the poorest countries in the world. The 2012 Human Development Index (HDI) ranked Niger 186 out of 187 countries (UNDP, 2013). Niger agriculture is overly influenced by a harsh climate and geography. Subsistence agriculture and stock rearing represent 40 % of the Niger Gross Domestic Product (GDP), being the second most relevant economic activity after services and employing three-quarters of Niger labor force (Geesing and Djibo, 2006).

Understanding price behavior along the chain is useful for economic agents when taking their decisions, as well as for policy makers and competition regulatory authorities. Hence, the link between different prices at different levels of the food marketing chain is a very interesting research topic not only in LDCs, but also in developed economies. In order to avoid biased results, assessment of price interactions at the consumer and producer levels should be based on flexible instruments that soundly capture the joint distribution function of

the variables considered. Correlation techniques such as the Spearman's rank and Kendall's tau correlation coefficients have been widely used to study dependence. An important limitation intrinsic to these techniques is that a single correlation coefficient is not usually enough to characterize dependence over the whole range of the distribution. For example, dependence in the extreme tails of the distribution may be different from dependence in the central areas and may be more relevant from a risk management point of view, i.e., economic agents and policy makers might be more interested in the dependence of prices during extreme weather or market events than during more frequent and less drastic changes.

Recent research has suggested the use of statistical copulas to assess dependence. Copulas are statistical instruments that combine univariate distributions to obtain a joint distribution (multivariate distribution) with a particular dependence structure. A key advantage intrinsic to copulas is that they are based on univariate distributions, instead of multivariate ones. This is especially important given the scarcity of multivariate distributions available from the statistical literature. These multivariate distributions include the normal and the t-Student and have been shown as inappropriate to assess behavior of the type of data we intend to study.

This paper is organized as follows. In the next section, a brief description of the millet market in Niger is offered. In section 3, a literature review of vertical price transmission analyses using time-series econometric techniques is presented. In section 4, the methodological approach is described. The fifth section is devoted to the empirical implementation to assess dependence between producer and consumer prices. The last section in this article offers the concluding remarks.

2. Millet market in Niger

The global financial crisis has led to a global economic recession and to increased commodity price levels and volatility. This has exacerbated food security problems that have hit poor countries specially hard. Around 60% of Niger population lives below the poverty line (Geesing and Djibo, 2006). Niger population relies on subsistence agriculture which has deteriorated in recent years and that satisfies 30% of the country's needs (WHO, 2006). Food purchases represent 63% of total household expenses (SANOGO, 2009). In 2012 about 40% (6.4 million people) of Niger's population was food insecure (UNOCHA, 2013) and undernourishment affected 12.6% of the population (FAO, 2012).

Cereals constitute the most relevant world food staple. World production of cereals in 2010 was 2.5 billion tons on an extension of land of 693 million hectares. In the same year, global cereal exports and imports were on the order of 340.3 and 336.3 million tons, respectively (FAOSTAT, 2010). In 2010, Africa produced 163 million tons, representing an increase on the order of 15% relative to 2005 and less than 7% of worldwide production. In the same year, African cereal exports and imports were 4 and 66.4 million tons, respectively, evidencing the continent's deficit in food production (FAOSTAT, 2010). Among the African countries, Niger cereal production expanded from 3.7 million tons in 2005 (FAOSTAT, 2005) to 5.2 million tons in 2010, representing an increase of around 71% (FAOSTAT, 2010) and around 3% of all cereals produced in Africa.

Millet is the staple food for more than one-third of the world's population, and the sixth most relevant cereal in world production (FAOSTAT, 2012). Global millet production expanded from 31 million tons in 2005 (FAOSTAT, 2005) to 32.5 million tons in 2010 (FAOSTAT, 2010). In 2010, international exports and imports of millet were estimated to be 357.3 and 470 thousand tons, respectively (FAOSTAT, 2010). Millet is extremely important for African economies that in 2010 devoted 21.5 million hectares to produce 16.7 million tons (FAOSTAT, 2010). Millet production is distributed among 37 countries, being Niger the third largest global producer after India and Nigeria. These three countries represent around 12% of total world millet production (FAOSTAT, 2010). The largest African producers are Nigeria (31.3%), Niger (23.3%) and Mali (8.3%) (FAOSTAT, 2010). The largest harvested millet area is found in Niger with 7.3 million hectares (representing a 24% growth rate since 2005), Nigeria with 4.4 million hectares and Sudan with 2.0 million hectares. African exports (imports) of millet were estimated to be on the order of 4.4 (141.3) thousand tons in 2010 (FAOSTAT 2010).

Millet represents the most relevant food staple for Niger's population of more than 16 million people. It is further the largest cereal crop produced in the country, representing 73% of all cereals produced in 2010 (FAOSTAT, 2010). In 2005, Niger production was 2.7 million tons and grew to be 3.8 million tons in 2010, an increase of around 69%. In the same year, millet consumption was around 3.8 million tons as well (USDA, 2010). Niger is the

third largest world importer of millet, after Sudan and Philippines, with around 43 thousand tons.

Our study focuses on millet price behavior in two markets: Maradi and Tillabéri. While Maradi represents a region where there is excess millet production, Tillabéri is a consumption zone. Distance between Maradi and Tillabéri markets is 779 km (Oxfam, 2013). Maradi's population is around 3.3 million people (MAE, 2012), 16.2% of which suffers from acute malnutrition (UNWFP, 2012). Maradi market is the first largest producer and consumer of cereals in Niger, with 1.2 million tons and 767 thousand tons, respectively (MAE, 2012). Millet, the first cereal in terms of Maradi production, reached 807 thousand tons (68% of total cereal production) and 1.5 million hectares in 2012 (MAE, 2012).

Tillabéri has a population of 2.7 million people (MAE, 2012) and around 16.6% of the population suffers from acute malnutrition (UNWFP, 2012). Tillabéri production of cereals is 821 thousand tons, while consumption is on the order of 563 thousand tons. Millet production in Tillabéri reached 692 thousand tons in 2012, grown on an area of 1.4 million hectares (MAE, 2012).

Consumer and producer price data required to conduct the analysis was supplied by Itermon Oxfam. Consumer prices for millet were available for both markets, given their economic relevance as consumption centers. However, producer price data are only available for the Maradi market. Conversations with Oxfam experts in Niger economy, recommended to take the Maradi producer price as representative of producer prices in both Maradi and Tillabéri, and assess the links between two pairs of prices: Maradi producer price – Maradi consumer price and Maradi producer price – Tillabéri consumer price. We follow this recommendation.

3. Literature review

Many empirical studies have addressed price transmission along the food marketing chain to study how prices are transmitted from producers to final consumers. Two main methodological approaches have been followed for such purpose: structural analyses that rely on economic theory, and time-series empirical analyses that identify empirical regularities in the data. Our work will follow the second methodological approach. Sound econometric analysis of time series data requires investigating their statistical properties. Empirical research has found that these data often violate the most common assumptions of conventional statistical inference methods, which may lead to obtaining completely spurious results. Time-series data have usually been found to be non-stationary and, when related, to share a tendency to co-move in the long-run (Myers, 1994). Cointegration and error correction models (ECM) have been introduced in the literature (Engle and Granger, 1987) to characterize non-stationary and cointegrated data and inform both on their short and long-run dynamics. Time-varying and clustering volatility, another common characteristic of time-series, is typically modeled through generalized autoregressive conditional heteroskedasticity (GARCH) models.

The work by Chang (1998) relies on Engle and Granger (1987) cointegration techniques, to study long run relationships among Australian beef prices at the farm, wholesale and retail levels. Evidence is found that all three prices are non-stationary and maintain a long-run equilibrium relationship, being the retail price, the one that drives price patterns. Price time series may also be characterized by asymmetric adjustment to long-run equilibrium. Recent literature in this area has relied on smooth or discrete threshold time-series models that usually allow for autoregressive and error correction patterns. The work by Abdulai (2002) analyzes the relationship between producer and retail pork prices in Switzerland, by employing threshold cointegration tests. Results indicate that price transmission between producer and retail levels is asymmetric, since increases in producer prices are transferred more rapidly to retailers than producer price declines. Using an asymmetric error-correction model, Von Cramon-Taubadel (1998) obtains the same results for the German pork market. Vavra and Goodwin (2005) use threshold vector error correction models (TVECM) to assess the links between retail, wholesale and farm level prices for the US beef, chicken and egg markets. Research results indicate that there are significant asymmetries in response to positive and negative price shocks. Asymmetries are apparent both in terms of speed and magnitude of the adjustment.

Evidence of asymmetric price transmission along the food marketing chain is found by Seo (2006), Saikkonen (2005), Goodwin and Holt (1999), Serra and Goodwin (2003), Meyer and von Cramon-Taubadel (2004), among others. TVECM are used by Pozo et al. (2011) to

examine price transmission among farm, wholesale and retail US beef markets. Results show that there is no evidence of asymmetric price transmission in any of the models. To the best of our knowledge, the work by Gervais (2011) is the first paper focusing on potential nonlinearities in both the long- and short-run price dynamics within a cointegration framework. Gervais (2011) studies the US pork marketing chain, from farm to consumer markets. Results indicate the importance of testing for linearity in the long-run relationship between prices. Results also show that a decrease in farm prices is eventually transferred to consumers.

While most of the literature has studied first-moment price patterns along food market chains, a few analyses have been concerned about price volatility spillovers. The work by Serra (2011) analyzes the impacts of the Bovine Spongiform Encephalopathy (BSE) outbreak on price volatility transmission along the Spanish beef marketing chain, by using a smooth transition conditional correlation (STCC) GARCH model. Results suggest that price volatilities at different levels of the marketing chain are negatively correlated during turbulent times. Rezitis and Stavropoulos (2011) assess price volatility interactions among producer and consumer broiler markets in Greece by means of multivariate GARCH (MGARCH) models. MGARCH results provide significant evidence of volatility persistence in producer and consumer markets. Buguk et al. (2003) utilize an exponential generalized autoregressive conditional heteroskedasticity (EGARCH) model to test for price volatility spillovers along the US catfish supply chain and find evidence of significant volatility interactions along this chain.

Uchezuba et al. (2013) investigate asymmetric price level and volatility spillovers along the broiler supply chain in South Africa. Threshold autoregressive (TAR) and momentum threshold autoregressive (M-TAR) models are used to investigate asymmetry in price first moments, whereas the EGARCH model is used to measure price volatility and the volatility spillover effect between retail and farm prices. Asymmetries characterize price level adjustments, with retail prices responding more rapidly to negative than positive changes in farm price. Results from the volatility model support significant asymmetric volatility spillover from the farm to retail level. More recently, other methodological approaches based on the use of statistical copulas have started to gain interest among economists interested in price transmission analyses. These methods rely on direct examination of the joint probability distribution function of the variables that are being studied and pay special attention to the nature of jointness between these variables. The work by Serra and Gil (2012) studies dependence between two pairs of prices: crude oil and biodiesel blend prices, and crude oil and diesel prices in Spain, with a special focus on this dependence during extreme market events. Statistical copulas are used for such purpose. Results prove asymmetric dependence between crude oil and biodiesel prices, which protects consumers against extreme crude oil price increases. Diesel prices, in contrast, equally reflect crude oil price increases and decreases. The work by Goodwin et al. (2011) studies the joint distribution of four North American lumber prices in different markets (Eastern Canada, North Central US, Southeast US, Southwest US). Copula models are used to obtain the correlation between prices at the geographical locations considered. Results indicate that market adjustments are generally larger in response to large price differences which reflect more substantial disequilibrium conditions.

The unpublished article by Qiu and Goodwin (2013) relies on the application of static and dynamic copula models to the empirical study of links between farm-retail and retail-wholesale prices for US hog/pork markets. Results indicate that farm and wholesale markets are more closely related to each other, while retail price adjustment is less dependent on the other two markets. Farm-retail and retail-wholesale price adjustments have relatively constant dependence structures. Also, results confirm the existence of dynamic and asymmetric behavior in price co-movements between the farm and retail markets. Positive upper and zero lower tail dependencies provide evidence that big increases in farm prices are matched at the retail level, while negative shocks at the farm level are less likely to be passed on to consumers. Our paper contributes to the literature by examining the dependence between producer and consumer markets in Niger, a country characterized by its insufficient food production and where food security issues are very relevant, using statistical copulas. To our knowledge, this is the first attempt to study vertical price transmission in LCD countries using this methodology.

4. Methodology

This analysis uses statistical copulas to characterize dependency along the food marketing chain in Niger millet markets. While the use of copula functions is common within the financial economics literature (see, for example, Patton, 2006 and 2012a; or Parra and Koodi, 2006), empirical studies that use copulas to assess dependency along the food marketing chain are very scarce. Copulas provide a natural way to measure dependency between two or more variables. A copula function is a multivariate distribution function defined on the unit cube $[0, 1]^n$, with uniformly distributed marginals. Copulas are based on the Sklar's (1959) theorem that shows that multivariate distribution functions characterizing dependence between n variables, can be decomposed into n univariate distributions and a copula function, the latter fully capturing the dependence structure between variables. This contrasts with the use of correlation coefficients between random variables as a measure of dependence. While correlations are highly popular due to the ease with which they can be calculated, they can be very misleading if random variables are not jointly elliptically distributed.

By focusing on modeling univariate distributions, the Sklar's theorem usually leads to the formulation of better models (Patton, 2006). Let F_1, \dots, F_n be the univariate distribution functions of n random variables (x_1, \dots, x_n) . H is assumed to represent the joint distribution function. According to the Sklar's theorem, there exists a copula $C(\cdot)$ that can be expressed as (Embrechts et al., 2001).

$$H(x_1, \dots, x_n) = C(F_1(x_1), \dots, F_n(x_n)) = C(u_1, \dots, u_n). \quad (1)$$

where $C(\cdot)$ is an n -dimensional distribution function with uniformly distributed margins $u_i \sim \text{Unif}(0,1)$, $i = 1, \dots, n$. The joint density function can be defined as:

$$h(x_1, \dots, x_n) = \prod_{i=1}^n f_i(x_i) c(u_1, \dots, u_n), \quad (2)$$

where c is the copula density and $f_i(x_i)$ are the univariate density functions of the random variables.

Different copula specifications represent different dependence structures. Our analysis will consider both elliptical (Gaussian copula) and Archimedean (Symmetrized Joe-Clayton-SJC copula) copulas. Elliptical copulas are based on the elliptical distribution, while Archimedean are a group of associative copulas that have the advantage of reducing dimensionality issues during the estimation process. Copulas may also be categorized as static and time-varying. A static copula relies on the assumption that parameters are constant over time, while dynamic copula parameters change with changing environment.

To model price dependency along the food marketing chain, the static and dynamic Gaussian copulas, the benchmark copulas in economics, are considered. While the static Gaussian copula provides a single measure of dependence (correlation) that is assumed to be constant over time, the dynamic version of this copula allows for time-changing dependence. As noted in the literature review above, many authors have suggested the presence of asymmetries in vertical price transmission within the food marketing chain. These asymmetries tend to be more pronounced as we move to extreme tails of the distribution (i.e., when price increases or declines are larger), which we capture through the static and dynamic symmetrized Joe-Clayton (SJC) specification. SJC allows for asymmetric dependence in any direction and nests symmetry as a special case (Ning, 2010).

Since our analysis is based on price pairs (producer and consumer Niger millet markets), $n = 2$. A bivariate Gaussian copula can be expressed as:

$$C_R^{Ga}(u, v; R_{12}) = \int_{-\infty}^{\Phi^{-1}(u)} \int_{-\infty}^{\Phi^{-1}(v)} \frac{1}{2\pi\sqrt{(1-R_{12}^2)}} \exp\left\{\frac{-(r^2 - 2R_{12}rs + s^2)}{2(1-R_{12}^2)}\right\} dr ds, \quad (3)$$

where R_{12} is the correlation coefficient of the corresponding bivariate normal distribution, $-1 < R_{12} < 1$, and Φ denotes the univariate normal distribution function. A drawback of the Gaussian copula is that it assumes that variables u and v are independent in the extreme tails of the distribution. Hence the Gaussian copula does not have lower and upper tail dependence. It thus represents dependence in the central region of the distribution.

The Symmetrized Joe-Clayton (SJC) copula is an extension of the Joe-Clayton copula which can be expressed as

$$C_{\tau^U, \tau^L}^{jc}(u, v) = 1 - \left(1 - \left\{[1 - (1 - u)^k]^{-\gamma} + [1 - (1 - v)^k]^{-\gamma} - 1\right\}^{-1/\gamma}\right)^{1/k}, \quad (4)$$

where $k = 1/\log_2(2 - \tau^U)$, $\gamma = -1/\log_2(\tau^L)$, $\tau^U \in (0, 1)$, and $\tau^L \in (0, 1)$. Joe-Clayton copula has two parameters, τ^U and τ^L , that measure the upper and lower tail dependence, respectively. This copula characterizes tail dependency, i.e., it models price behavior during extreme events. More specifically, it models the probability that relevant increases (declines) in the prices studied occur together. These measures of the upper and lower tail dependence can be expressed as follows:

$$\lim_{\varepsilon \rightarrow 0} \Pr[U \leq \varepsilon | V \leq \varepsilon] = \lim_{\varepsilon \rightarrow 0} \Pr[V \leq \varepsilon | U \leq \varepsilon] = \lim_{\varepsilon \rightarrow 0} C(\varepsilon, \varepsilon) / \varepsilon = \tau^L \quad (5)$$

$$\lim_{\delta \rightarrow 1} \Pr[U \leq \delta | V \leq \delta] = \lim_{\delta \rightarrow 1} \Pr[V \leq \delta | U \leq \delta] = \lim_{\delta \rightarrow 1} (1 - 2\delta + C(\delta, \delta)) / (1 - \delta) = \tau^U \quad (6)$$

The Joe-Clayton copula implies an asymmetric dependence, even when $\tau^U = \tau^L$. The Symmetrized Joe-Clayton (SJC) copula allows overcoming this problem (Patton, 2006) and can be specified as:

$$C_{\tau^U, \tau^L}^{sjc}(u, v) = 0.5 \left(C_{\tau^U, \tau^L}^{jc}(u, v) + C_{\tau^U, \tau^L}^{jc}(1 - u, 1 - v) + u + v - 1 \right) \quad (7)$$

The dynamic version of the Gaussian copula allows the correlation parameter to evolve as shown in equation (9) below (Vogiatzoglou, 2010):

$$Q_t = (1 - \alpha - \beta) \cdot \bar{Q} + \alpha \varepsilon_{t-1} \cdot \varepsilon'_{t-1} + \beta \cdot Q_{t-1}, \quad (8)$$

$$R_{12,t} = \tilde{Q}_t^{-1} Q_t \tilde{Q}_t^{-1}, \quad (9)$$

where \bar{Q} is the sample covariance of ε_t , \tilde{Q}_t is a square matrix with zeros as off diagonal elements and diagonal elements the square root of those of Q_t . Following Patton (2006), the dynamic version of the Symmetrized Joe-Clayton (SJC) copula is defined as:

$$\tau_t^U = \Lambda \left(\omega_U + \beta \tau_{t-1}^U + \alpha_U \frac{1}{10} \sum_{i=1}^{10} |u_{1,t-i} - u_{2,t-i}| \right), \quad (10)$$

$$\tau_t^L = \Lambda \left(\omega_L + \beta \tau_{t-1}^L + \alpha_L \frac{1}{10} \sum_{i=1}^{10} |u_{1,t-i} - u_{2,t-i}| \right), \quad (11)$$

where $\Lambda = (1 + e^{-x})^{-1}$ denotes the logistic transformation that keeps the parameters in the (0, 1) range.

Patton (2006) shows that consistent and asymptotically normal copula parameters can be obtained through a two-stage estimation procedure. In the first stage, marginal distribution models specified and estimated. In the second stage, parameters of the copula model are

estimated. The joint density can be parametrized as follows: $H(\xi) = C(F_1(\phi_1), \dots, F_n(\phi_n); \theta)$, where $\xi = (\phi_1, \dots, \phi_n, \theta)$ is the vector that contains both marginal parameters (ϕ_1, \dots, ϕ_n) , and θ that denotes the copula parameters characterizing dependence. The joint density can be expressed as:

$$h(x_1, \dots, x_n; \xi) = \prod_{i=1}^n f_i(x_i; \phi_i) c(F_1(x_1; \phi_1), \dots, F_n(x_n; \phi_n); \theta) \quad (12)$$

By taking logarithms of expression (12) and summing across observations ($j = 1, \dots, T$) the log likelihood function can be derived and is given by

$$\ell(x_1, \dots, x_n; \xi) = \frac{1}{T} \sum_{j=1}^T \left(\sum_{i=1}^n \log(f_i(x_{i,j}; \phi_i)) + \log(c(F_1(x_{1,j}; \phi_1), \dots, F_n(x_{n,j}; \phi_n); \theta)) \right) \quad (13)$$

Equation (13) can be decomposed into marginal log likelihoods and the copula log likelihood:

$$\ell(x_1, \dots, x_n; \xi) = \sum_{i=1}^n \ell(\phi_i) + \ell(\phi_1, \dots, \phi_n; \theta) \quad (14)$$

By maximizing the marginal log likelihoods $\ell(\phi_i)$, parameters of the marginal distributions are estimated. In the second stage, copula parameters are derived by optimizing the corresponding copula log likelihood $\ell(\phi_1, \dots, \phi_n; \theta)$, conditional on the results from the first stage (Patton, 2012b). The two-stage estimation technique can be formalized as follows (Vogiatzoglou, 2010):

$$\hat{\phi}_i = \arg \max_{\phi_i} \frac{1}{T} \sum_{j=1}^T \log f_i(x_{i,j}; \phi_i), \quad (15)$$

$$\hat{\theta} = \arg \max_{\theta} \frac{1}{T} \sum_{j=1}^T \log c(F(x_{1,j}; \phi_1), \dots, F(x_{n,j}; \phi_n); \theta) \quad (16)$$

The most attractive feature of copula functions is that the marginal distributions do not necessarily have to come from the same families. Marginal models allow deriving standardized, independent and identically distributed (*i.i.d*) residuals from the filtration. The *i.i.d* residuals are then transformed to *Unif*(0,1) using the non-parametric empirical cumulative distribution function (CDF). The empirical CDF method is especially convenient when the true distribution of the data is not known. The theory of copula applies to stationary time-series. The Dickey and Fuller (1979), Perron (1997) and KPSS (1992) tests used to test for unit roots are run on our data. Results support the presence of a unit root in both millet producer and consumer prices. The price pairs considered are also found to maintain equilibrium parity by implementing the Johansen (1988) cointegration test. The univariate models for the producer and consumer price pairs considered (P_p, P_c) are consequently specified as an error-correction type of model (ECM) (equations 17 and 19). Model residuals are modeled by means of a GARCH (1,1) specification in order to allow for time-varying and clustering volatility (equations 18 and 20).

$$\Delta P_{c,t} = \alpha_c + \lambda_c \delta_{t-1} + \sum_{i=1}^2 \alpha_{cct} \Delta P_{c,t-i} + \sum_{i=1}^2 \alpha_{cpi} \Delta P_{p,t-i} + \varepsilon_{c,t} \quad (17)$$

$$\sigma_{c,t}^2 = \omega_c + \omega_{c1} \varepsilon_{c,t-1}^2 + \omega_{c2} \sigma_{c,t-1}^2 \quad (18)$$

$$\Delta P_{p,t} = \alpha_p + \lambda_p \delta_{t-1} + \sum_{i=1}^2 \alpha_{pcit} \Delta P_{c,t-i} + \sum_{i=1}^2 \alpha_{ppi} \Delta P_{p,t-i} + \varepsilon_{p,t} \quad (19)$$

$$\sigma_{p,t}^2 = \omega_p + \omega_{p1} \varepsilon_{p,t-1}^2 + \omega_{p2} \sigma_{p,t-1}^2 \quad (20)$$

where ΔP_{jt} , $j = p, c$ is the first difference of logged producer and consumer prices, $\alpha_{j,n,i}$, $j, n = p, c$ are short-run dynamic parameters that measure the influence of past price differences on current differences. The error correction term derived from the long-run equilibrium relationship is represented by δ_t , thus λ_j , $j = p, c$ measures the long-run price dynamics. ε_{jt} , $j = p, c$ are normally distributed error terms.

Conducting goodness of fit tests on the marginal models is essential for copula model estimation. The LM tests of serial independence of the first four moments of U_t and V_t are estimated by regressing $(u_t - \bar{u})^k$ and $(v_t - \bar{v})^k$ on 10 lags for each price series, for $k = 1, 2, 3, 4$. We also use the Kolmogorov-Smirnov (KS) test to make sure that the transformed series are $Unif(0, 1)$. Following Zhu et al. (2008), to select the optimal copula we use the Akaike's information criterion (AIC) and the Bayesian information criterion of Schwarz's (BIC).

5. Empirical analysis

Intermon Oxfam made available monthly millet producer prices in Maradi (Mp) and consumer prices in Maradi and Tillabéri (Mc , Tc , respectively) for the period from January 1990 to December 2010, yielding a total of 252 observations. Prices are expressed in Central African Francs (CFA) per kilo and studied in pairs (Mp , Mc) and (Mp , Tc). Logarithmic transformations of price series are used in the empirical analysis. Table 1 presents summary statistics for first differenced logged prices series. Standard unit roots tests were carried out and results, available from authors upon request, show that price time series are non-stationary.

Johansen's (1988) cointegration tests are used to assess the existence of an equilibrium relationship between the pairs of prices studied. Since prices are expressed in logarithms, cointegration parameters can be interpreted as price elasticities. Short-run parameters in the ECM represent proportionate changes. Test results suggest that there is a long-run relationship between producer prices in the Maradi millet market, with Maradi and Tillabéri consumer prices (see table 2).

Table 1. Summary statistic for first log-differences prices series.

	Mp	Mc	Tc
Mean	0.005	0.004	0.002
Standard Deviation	0.007	0.008	0.008
T-statistic	0.617	0.582	0.264
Skewness	-1.126	-1.014	-0.052
Kurtosis (excess)	3.271**	3.122**	4.274**
Jarque-Bera statistic	164.936**	144.986**	191.169**
ARCH LM statistic	8.109**	17.977**	7.629**
Number of observations			251

Note: **indicates rejection of the null hypothesis at the 5% significance level. The skewness and kurtosis and their significance tests are from Kendall and Stuart (1958). The Jarque-Bera is the well-known test for normality. The ARCH LM test of Engel (1982) is conducted using 2 lags.

Producer and consumer markets are positively correlated, with price elasticities being higher when the two markets coincide geographically (0.96 vs 0.72). Lower transaction costs due to proximity are likely to facilitate price transmission along the food marketing chain. A chi-square test of weak exogeneity for long-run parameters within the Johansen's framework, shows that consumer prices are responsible for maintaining such equilibrium by reacting to the deviations that can occur (results are available from authors upon request).

We base our empirical analysis on univariate error-correction type of models. Results from univariate ECM-GARCH model estimation are presented in Tables 3 and 4 for (Mp , Mc) and (Mp , Tc) pairs of prices, respectively. Short-run parameters show that current changes in Maradi producer prices have a relevant autoregressive component.

As noted above, Maradi producer prices are exogenous for long-run parameters. The conditional variance equation shows that past market shocks contribute to increase Maradi producer price volatility. GARCH (1,1) model parameters are all positive, which indicates that in-sample and out-sample variance estimates are positive. Since $\omega_{Mp1} + \omega_{Mp2} < 1$, we

can conclude that the GARCH process is stationary, being the unconditional long-run variance ($\sigma_{Mp}^2 = \omega_{Mp} / (1 - \omega_{Mp1} - \omega_{Mp2})$) around 0.015

Table 2. Johansen λ_{trace} test for cointegration and cointegration relationship

($Mp - Mc$)				($Mp - Tc$)			
H_0	H_a	λ_{trace}	$P - value$	H_0	H_a	λ_{trace}	$P - value$
$r = 0$	$r > 0$	52.791	0.000	$r = 0$	$r > 0$	46.351	0.000
$r \leq 1$	$r > 1$	6.034	0.208	$r \leq 1$	$r > 1$	5.822	0.237
Cointegration relationship				Cointegration relationship			
$Mc - 0.963^{**} Mp - 0.256^{**} = v_{McMp,t}$ (-47.098) (-2.751)				$Tc - 0.718^{**} Mp - 1.724^{**} = v_{TcMp,t}$ (-18.086) (-9.493)			

Note: r is the cointegration rank. ** denotes statistical significance at the 5% level.

Current changes in the Maradi consumer prices are explained by past changes in the Maradi producer market, as well as by the deviations from the long - run disequilibrium (table 3). It is thus the retail market that makes the necessary price adjustments so that the millet market is in equilibrium. The conditional variance equation shows that both past market shocks and volatility contribute to destabilize the consumer market in Maradi. The univariate GARCH (1,1) model process provides evidence of a stationary volatility process, and GARCH parameters lead to an unconditional variance $\sigma_{Mc}^2 = 0.013$. Price volatilities in producer and consumer markets are thus very similar, being the consumer price slightly less volatile. The fact that retail prices cannot immediately and fully respond to producer price changes leads to more stable price behavior.

In the next lines, we discuss Tillabéri millet price behavior derived from the (Mp, Tc) price pair analysis, presented in table 4. Tillabéri consumer price level changes depend on their own lags, as well as on disequilibrium from the long-run parity. Relative to Maradi consumer price adjustment, Tillabéri consumer price changes show a slow adjustment to disequilibrium, which is again indicative that geographical distance slows price transmission. Supply shortage characterizing Tillabéri market is probably the underlying reason of high consumer price instability: the unconditional long-run variance equilibrium for Tillabéri consumer prices is $\sigma_{Tc}^2 = 0.023$. This volatility is strongly affected by past market shocks.

Table 3. Result for the univariate ECM-GARCH (1, 1) model for price pair (Mp, Mc)

Variable	Mp	Mc
$\Delta P_{Mp,t-1}$	0.329** (0.060)	0.211** (0.062)
$\Delta P_{Mc,t-1}$	-0.117** (0.042)	-0.079 (0.066)
$\mathcal{S}_{McMp,t}$	0.015 (0.057)	-0.481** (0.072)
ω_i	0.008** (0.001)	0.009** (0.001)
ω_{i1}	0.421** (0.131)	0.086** (0.049)
ω_{i2}	0.059 (0.055)	0.215** (0.044)
Ljung-Box Q(10)	12.689	11.677

Note: ** denotes statistical significance at the 5% level.

The Ljung-Box test results presented in tables 3 and 4 allow accepting the null of no autocorrelated residuals. The LM tests (table 5) implemented to test for the independence of

the first four moments of the transformed variables provide evidence that the models are well specified. We also applied the Kolmogorov–Smirnov (KS) test that confirms that the transformed series are *Unif*(0,1) (Patton, 2006).

Table 4.Result for the univariate ECM-GARCH (1, 1) model for price pair (Mp, Tc)

Variable	Mp	Tc
$\Delta P_{Tc,t-1}$	0.209** (0.074)	0.417** (0.056)
$\Delta P_{Mp,t-1}$	0.007 (0.064)	0.003 (0.076)
$\mathcal{S}_{TcMp,t}$	-0.062 (0.048)	-0.252 ** (0.051)
ω_i	0.008** (0.001)	0.005** (0.001)
ω_{i1}	0.381** (0.081)	0.621** (0.187)
ω_{i2}	0.067 (0.048)	0.158** (0.065)
Ljung-Box Q(10)	12.574	19.902

Note: ** denotes statistical significance at the 5% level.

The Akaike's information criterion (AIC) and Bayesian information criterion of Schwarz's (BIC) are applied to choose the optimal specification of the copula (see table 6). Information criteria recommend the static Gaussian and the Static (SJC) copulas, as the copulas providing the best fit. Parameters estimated for these two copulas are presented in tables 7 and 8. Results of dynamic copulas are thus not presented, as they have lower data fitting capacity.

Table 5.Results for tests on the transformed variables

	$Mp - Mc$	
	<i>Maradi</i> producer (Mp)	<i>Maradi</i> consumer (Mc)
First moment LM test	0.561	0.924
Second moment LM test	0.215	0.390
Third moment LM test	0.371	0.570
Fourth moment LM test	0.421	0.731
(K-S) test	0.809	0.871
	$Mp - Tc$	
	<i>Maradi</i> producer (Mp)	<i>Tillabéri</i> consumer (Tc)
First moment LM test	0.450	0.890
Second moment LM test	0.109	0.868
Third moment LM test	0.208	0.947
Fourth moment LM test	0.316	0.697
(K-S) test	0.401	0.535

Note: this table presents p-values from LM test of serial independence (Patton, 2006) of the first four moments of U_t and V_t and Kolmogorov–Smirnov (K-S) tests.

In the following lines, we discuss the results from copula estimation. The parameters derived from static Gaussian copula presented in table 7 measure dependency in the central region of the bivariate distribution. They provide evidence that there is a positive correlation between prices at different market levels. As a result, an increase in Maradi producer prices leads to an increase in Maradi and Tillabéri consumer prices, being the link especially relevant when the two markets are geographically close. This is compatible with cointegration and error-correction model results.

Table 6.AIC and BIC criteria to evaluate and select the optimal copula

Copula function	($Mp - Mc$)		($Mp - Tc$)	
	Criteria		Criteria	
	AIC	BIC	AIC	BIC
Static Gaussian copula	-218.385	-214.859	-36.986	-33.461
Dynamic Gaussian copula	-249.231	-242.189	-35.005	-27.763
Static (SJC) copula	-277.813	-270.771	-34.862	-27.819
Dynamic (SJC) copula	-253.389	-232.260	-29.514	-8.386

Table 7.Results for static Gaussian copula

	($Mp - Mc$)	($Mp - Tc$)
$\bar{\rho}$	0.765** (0.011)	0.380** (0.046)
Copula log likelihood	-110.192	-19.493

Note: ** denotes statistical significance at the 5% level.

Previous research on vertical price transmission shows that retailers tend to pass price increases on to consumers more quickly and completely than price declines, specially when the magnitude of the changes is relevant. The SJC studies dependency in the extreme tails of the distribution and allows for asymmetric price behavior. The upper and lower tail dependence parameters show dependency during extreme increases and extreme decreases of prices. (Mp , Mc) price pairs show a stronger dependence during market price increases (the correlation coefficient is 11% higher for market upturns, relative to downturns), i.e., price increases are more likely to occur together than price declines. Hence, retailers are more likely to increase prices than to reduce them.

Table 8.Results for static SJC copula

	($Mp - Mc$)	($Mp - Tc$)
τ^U	0.710** (0.044)	0.228** (0.080)
τ^L	0.640** (0.072)	0.163** (0.081)
Copula log likelihood	140.907	19.431

Note: ** denotes statistical significance at the 5% level.

6. Concluding remarks

Developing countries' population suffers from poverty, food insecurity and nutritional deficiencies. While food price-level transmission along the marketing chain in developing economies has been widely assessed by previous research, less attention has been paid on less developed countries, mainly due to a lack of price data. Since the food price crisis in 2007/2008, economic research has paid substantial attention to food price behavior, given the significant impacts that it has at the political, economic and social levels. Our work focuses on characterizing millet price behavior along the Niger food marketing chain.

The contribution of this paper to the literature is twofold. On the one hand, it studies price behavior of food staples in less developed countries, thus enlarging a literature that is rather scarce due to data limitations. Second, it does so by using statistical copulas, a method that has just started to be used in vertical price analysis. An attractive feature of these models is that they are specially suited when no obvious choice for the multivariate density characterizing price dependence exists. Copulas allow researchers to focus on modeling univariate distributions instead of the multivariate ones, which usually leads to the construction of better models.

The analysis focuses on the dependence between two pairs of prices: Maradi producer and consumer markets, and Maradi producer and Tillabéri consumer markets. While Maradi

represents a region where there is excess millet production, Tillabéri is a deficit zone. Results show that Niger millet markets are dominated by producer markets instead of consumer prices. Retail prices are the prices that guarantee maintenance of the long-run equilibrium relationship. This contrasts with market price behavior in developed countries, usually found to be dominated by retail chains.

Research results from applied Gaussian copula indicate that there is evidence of a positive correlation between prices at different market levels for both price pairs considered. Correlation is especially strong between geographically close markets. SJC copulas, that show dependence during extreme market events and allow for asymmetries, show differences between upper and lower tail dependence for both pairs of prices. These differences show a stronger tendency of prices to increase than to decline. Asymmetries are bigger as distance between the markets increases. The fact that a millet consumer price are increased more quickly and completely than reduced is worrisome in a country where millet is a food staple and where a relevant portion of the population suffers from famine.

In being the producer the dominant price within the chain, producer price stabilization policies adopted in Niger will bring stability to consumer markets as well. Geographical distance between producer and consumer markets may however reduce the effectiveness of the adopted policies. Implementation of policies such as early detection of locust attacks, adoption of drought-resistant seed varieties, or the promotion of local reserve initiatives, will benefit both producers and consumers. Implementation of such policies is thus specially urgent in a country where famine is worrisome, food price risk is one of the highest policy concerns and where consumers suffer from the cumulative effects of price asymmetries.

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