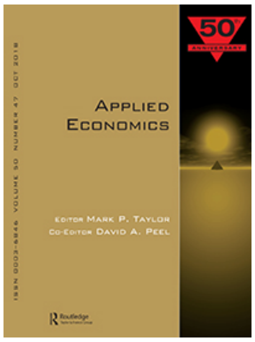

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Vertical price transmission in the Egyptian tomato sector after the Arab Spring

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ABSTRACT
This study assesses price transmission along the Egyptian tomato food marketing chain in the period that followed the Arab Spring, which accentuated economic precariousness in Egypt. Static and time-varying copula methods are used for this purpose. Results suggest a positive link between producer, wholesaler and retailer tomato prices. Such positive dependence is characterized by asymmetries during extreme market events that lead price increases to be transferred more completely along the supply chain than price declines.

KEYWORDS
Food prices; asymmetric price transmission; dependence analysis; static and time-varying copula

JEL CLASSIFICATION
C22; C51; Q11

I. Introduction

The 2007/2008 food crisis affected several countries socially and politically. The second food price crisis started at the end of 2010 that leads to series of revolutions so-called Arab Spring began with Tunisia, Egypt, Syria, Libya and Yemen (Ciezadlo 2011). The prevailing economic situation in Egypt before the 2011 Arab Spring[1] was challenging and partly characterized by high unemployment rates, specially among youth, unfair wage structures and high food and energy prices. The revolutions accentuated economic precariousness: GDP growth rates decreased from 5.1% in 2010 to 2.2% in 2012, while inflation measured through the consumer price index grew by 9.5% in 2013 (Bank 2013). Inflation is bigger if a longer time span is considered: from the first week of January 2011 till the first week of December 2013, Egyptian food prices increased by 17.7% (Egyptian Food Observatory 2013). This economic downturn led to food price instability, food shortages and higher poverty.

Food prices increased as a result of economic instability and political upheaval. Evidence of strong relationship between food prices and political unrest specially in poor counters have been found (Bellemare 2015; Arezki and Brückner 2011). In 2013, more than 79% of family income was spent on food and more than 80% of Egyptian population earned insufficient income to cover consumption needs. According to the Egyptian Center for Economic and Social Rights (ECESR, 2013), the poverty rate increased from 21.6% in 2008/2009 to 26.3% in 2012/2013. Rising poverty worsened food insecurity that increased from 14% of the Egyptian population in 2009 to 17.2% (13.7 million people) in 2011 (Egyptian Center for Economic and Social Rights (ECESR) 2013). Undernourishment, on the other hand, represented more than 5% of Egyptian population in the 2011–2013 period (Africa Food Security and Hunger 2014).

Egyptian consumers have used different strategies to cope with recent food price increases: food purchases have been curbed down by 12.2% and more than 26% of consumers have opted for lower quality food products at cheaper prices (Egyptian Food Observatory 2013). Ensuring food security is a major issue specially in developing countries. According to FAO (2015), the dimensions of the food security are the availability, physical access, food utilization, stability over time (shocks) and economic access. To rendering the population in Egypt food secure, stability in

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[1]Arab Spring were a series of revolutions that started in Tunisia and Egypt and ended in Yemen. On 25 January 2011, a protest was held in Egypt calling for the end of the Mubarak dictatorship and protesting against economic and living conditions, corruption and injustice. After the Egyptian revolution, food prices increased significantly (Jensen 2011) for a number of reasons, including high gasoline prices and lack of security that led to increase of the transportation cost and food prices as well.

domestic food price level index is one of the essentials in countries where food consists a big part of the consumers budget (Coates 2013; Santeramo 2015b). Assessing food consumer price formation requires analysing how food prices are transmitted along the food marketing chain, from agricultural producers to final consumers.

Understanding price behaviour along the food marketing chain is very useful to assess the functioning of food production, processing and distribution markets, their competition and integration level. Vertical price transmission analyses can help identifying market -failures and are a good indicator of the degree of competitiveness and effectiveness of market performance. Competitive behaviour is rare in less developed countries (LDCs) due to distinctive market characteristics such as excessive government intervention, corruption, deficient infrastructures etc. Since prices drive resource allocation and production decisions, price transmission information is useful for economic agents when taking their economic decisions, policymakers and competition regulatory authorities. Hence, the link between different prices at different levels of the food marketing chain is a very interesting research topic in LDCs. This article characterizes the relationship between producer and wholesaler price levels, and between wholesaler and consumer price levels of tomato markets in Egypt. The analysis is of a pairwise nature. Pairwise analyses are usual in the price transmission literature and represent a natural avenue for studying price relationships (Goodwin and Piggott 2001). Lack of food price data in LDCs is the reason underlying the scarcity of studies on price behaviour in these countries. This increases the interest of the proposed analysis.

From 2008 to 2013, 6 years of the Global Development Alliance (GDA) project initiated by ACDI/VOCA, USAID, Heinz International and 13 domestic tomato processors. The main aim of this project is to enhance the capacity building and the income of the tomato farmers in Egypt. The implementation of such projects has positive impacts on tomato market (USAID 2016). Thus, it was necessary to clarify the role of this project to influence the tomato prices in Egyptian market, specially in the period after the revolution in which food prices were instable. The objective of this research article is to shed light on this matter by focusing on tomato sector in Egypt after Arab spring.

Sound assessment of price links requires knowledge of the joint distribution of the prices considered. The methods of error correction type or vector autoregressive of models have been commonly used under the assumption that the joint price distribution is Gaussian or *t*-Student. However, univariate distributions of economic time series are usually found to be characterized by excess kurtosis, skewness and nonnormality. Further, related price series may show asymmetric dependence, which is an indicator of multivariate nonnormality (Patton 2006). As a result, the Gaussian and the *t*-Student distributions have been shown as inappropriate to assess behaviour of the type of data we intend to study. Inadequate assumptions of multivariate distributions will lead to biased parameter estimates. Further, since the range of available multivariate distributions is limited, this limits how multivariate dependence can be modelled (Parra and Koodi 2006).

Assessment of dependence between producer, wholesaler and retailer levels should be based on flexible instruments that soundly capture the joint distribution function of the variables considered. Recent research has suggested the use of statistical copulas as an alternative. 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 specially important given the scarcity of multivariate distributions available from the statistical literature.

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

II. Tomato market in Egypt

World production of vegetables in 2012 was 1.1 billion tons on an extension of land of 57.2 million hectares. Africa produced 74.1 million tons, representing more than 6.5% of worldwide production (FAOSTAT 2012). Egypt vegetable production expanded from 18.3

million tons in 2006 (FAOSTAT 2006) to 19.8 million tons in 2012, representing an increase of 8.2% (FAOSTAT 2012) and 26.7% of all vegetables produced in Africa. Tomato is the most relevant vegetable in terms of world production and consumption (FAOSTAT 2012). Global tomato production expanded from 131.3 million tons in 2006 (FAOSTAT 2006) to 161.7 million tons in 2012 (FAOSTAT 2012). Egypt is the fifth largest global tomato producer after China, India, United States and Turkey. These five countries jointly represent 62% of total world tomato production (FAOSTAT 2012). Tomato is extremely important for African economies, which is devoted 21.5 million hectares to produce 17.9 million in 2012, roughly a quarter of the vegetables produced in Africa (FAOSTAT 2012).

Table 1 presents comparison between tomato sectors in Egypt, United States and Spain.[2] In 2012, Egyptian tomato production was higher than Spanish production by 47%, and less than United States by 65% (FAOSTAT 2012). The tomato farmers in Egypt produced 82 t per feddan[3] using manual labour, while in California, the farmers produced around 50 t using new technologies in the same size of land (Boutros 2014). Florida and California are the highest regions of tomato production in United States. California is the major tomato producer with 70% of US production and 96% of all processing tomato production. Florida is the second highest tomato producer in United States. With long session from October to June, Florida provides United States fresh tomatoes in winter season beside the greenhouse. Import is an essential component for tomato industry in United States with more than 1.5 million tons (one-third of the fresh tomato consumption). Most of the tomatoes are imported from Canada and Mexico 27% and 71%, respectively. The trade of tomatoes is large all over the year except August and September, when the local tomatoes are available that makes the price decrease (USDA 2016).

Table 1. Compare between tomatoes sectors in Egypt, Spain and United States in 2012.

	Egypt	Spain	United States
Production quantity (per million/t)	8.62	4.46	13.26
Yields (per thousand/ha/hg)	398.59	832.95	868.13
Area harvested (per thousand/ha)	216.39	48.60	152.69
Imports (per million/t)	0.015	0.93	1.54
Exports (per thousand/t)	23.55	901.65	211.59

Spain is the second higher producer of tomatoes in Europe after Italy, with 35% of all tomatoes produced in Europe and 5.5% of all over the world production. Most of the Spanish tomato production concentrated in Almería, Canary Islands, Valencia and Murcia. Spanish tomato production is available all the year. During the period from June to September, tomatoes are grown in open areas, while it produced in the greenhouse from January to May (ICEX 2015). Spain is the major exporter of the tomatoes to EU countries with 602.5 thousand tons in 2012, which represent 94% of all tomatoe exported from Spain. Most of tomatoes are exported to Germany, France and UK representing 22%, 16% and 14.5%, respectively. The main destination out of EU was Russia with 19.3 thousand tons. Spanish tomato import was 93 thousand tons, most of these tomatoes are imported from Portugal (ITC 2012).

Tomato is the first vegetable in terms of consumption and production in Egypt. In 2012, tomato harvest in Egypt exceeded 8.6 million tons, grown on more than 216 thousand hectares, representing 28% of the area cultivated with vegetable crops (FAOSTAT 2012). While tomatoes are grown only in open areas and in different regions in Egypt and could be cultivated three times throughout the year in spring, winter, and inter seasonal period, most of the production occurs in Upper Egypt, specially in the governorate of Qena (SIS 2013). Egypt, with half of tomato production, is the largest producer in Africa (FAOSTAT 2012). Egyptian exports of tomato were 23.5 thousand tons in 2012, and the main destinations were the Kingdom of Saudi Arabia, Libya, Netherlands and UK. Egypt imported small volumes of tomato (146 t) which came from Jordan.

Income derived from tomatoes fluctuates highly, being price instabilities one of the main reasons. Net returns in 2007 were on the order of 170 US$ per feddan. In winter 2011/2012, net returns increased to 3000 US$ per feddan and decreased to be 1200 US$ feddan in the summer 2012 (USDA 2014). Most production is channelled through two main wholesale markets in Egypt: El Abour market in Cairo and El Hadra market in Alexandria and subsequently distributed to retail markets after tomatoes have been sorted, processed and repackaged.

[2]Comparison between tomato sectors in Egypt, United States and Spain could put the readers into a context.
[3]Feddan is an Egyptian area measurement unit equivalent to acre.

Small and poor tomato producers suffer specially from high price instability in local markets. Further, they often rely on the black market, where prices are usually very high, to acquire their inputs (Boutros 2014). In order to improve economic sustainability of small tomato producers, a public–private partnership was formed between USAID, ACDI-VOCA, Heinz International and 13 domestic tomato processors. The partnership helped improve the capacity of smallholder farmer associations to supply the industry with large and consistent tomato quantities and increased producer market outlets. Currently, smallholder farms' associations sell at least 30% of their production through forward contracts to processor companies that protect against price risk (USDA 2014).

III. Literature review

According to their methodological approach, price transmission analyses can be classified into structural and non-structural studies. While structural models rely on economic theory, non-structural analyses identify empirical regularities in the data. Our approach to studying price transmission along the Egyptian marketing chain is based on non-structural time-series models. Time-series data often violate the most common assumptions of conventional statistical inference methods, which may lead to obtaining completely spurious results. Cointegration and error-correction models (ECMs) have been introduced in the literature (Engle and Granger 1987) to characterize nonstationary and cointegrated data and inform both on their short- and long-run time variation. Time-varying and clustering volatility, another common characteristic of time-series, is typically modelled through generalized autoregressive conditional heteroscedasticity (GARCH) models.

The work by Chang and Griffith (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 often display asymmetric adjustment to long-run equilibrium. Recent literature in this area has relied on smooth transition or discrete threshold time-series models that usually allow for autoregressive and error correction patterns. The article by Abdulai (2002) assesses the relationship between producer and retail pork prices in Switzerland, by employing threshold cointegration tests. Evidence has found that increases in producer prices have transferred more rapidly to retailers than producer price declines. Using an asymmetric ECM, von Cramon-Taubadel (1998) obtains the same results for the German pork market. Vavra and Goodwin (2005) use threshold vector ECMs to appraise 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 both terms of speed and magnitude of the adjustment, in response to positive and negative price shocks. Evidence of asymmetric price transmission along the food marketing chain have also found by Seo (2006), Saikkonen (2005), Goodwin and Holt (1999), Serra and Goodwin (2003) and Meyer and von Cramon-Taubadel (2004), among others.

There are few studies that have addressed vertical price transmission along the food chain in developing countries. Guvheya, Mabaya and Christy (1998) assess vertical price transmission in Zimbabwe tomato market using causality and Houck (1977) methods. While price transmission between farm and wholesale market levels is found to be asymmetric, price transmission from wholesale to retail markets is symmetric. Iran horticultural markets (date and pistachio) have been studied by Moghaddasi (2008). Houck (1977) and ECM approach have been used to characterize the pistachio and date market. Results indicate that there is asymmetry in price transmission from farm to retail markets. Granger and Lee (1989) asymmetric ECM is used by Acquah (2010) to examine and confirm existence of asymmetry in price transmission between wholesaler and retailer maize prices in Ghana.

Negassa (1998) focuses on vertical price transmission in grain markets in Ethiopia by using correlation coefficients and casualty methods, who finds evidence of symmetries. Minten and Kyle (2000) examines price asymmetry in urban food markets in Zaire. Evidence is found that prices are symmetrically passed between producer and wholesaler market levels but transmitted asymmetrically between wholesaler–retailer markets. Alam et al. (2010) apply an ECM on rice market prices in Bangladesh. Results indicate that prices are positively linked and wholesalers dominate the prices in the rice chain. Evidence of asymmetric price transmission has also been found. The study by Amikuzuno and Ihle (2010) analyses the tomato markets in the most important five tomato markets in Ghana, by applied Johansen co-integration model. Results reveal that the five markets are integrated and the prices transmitted quickly to these tomato markets in Ghana.

Most of studies found different explanations for the behavioural of the asymmetries in vertical price transmission (AVPT); these include market power, government interventions, inventory management, perishable and non-perishable products and market information (Santeramo and von Cramon-Taubadel 2016).

Mohanty, Peterson and Kruse (1995), Griffith and Piggott (1994) and Tappata (2009) suggest that market power and market competition lead to asymmetric price transmission. Evidence of asymmetric price transmission as a result of government interventions is found by Peltzman (2000), Bailey and Brorsen (1989) and Kinnucan and Forker (1987). While inventory management may lead as well to asymmetric price transmission (Blinder, 1982; Balke et al., 1998; Reagan and Weitzman, 1982), the study by Bailey and Brorsen (1989) concludes that asymmetric price transmission reflects the asymmetries in the market information.

Kim and Ward (2013) assess the food price transmission in short and long run; they have focused on recursive methods across 100 food commodities in United States. Results indicate that there is strong linkage between prices in short and long run, but this strong relation tends to be vanished over time. Results also imply that price increases are likely to be passed to retail's level quicker than price declines.

The work by Stephens et al. (2011) to understand the price transmission between spatially distinct markets might vary during periods with and without physical trade flows, through estimating generalized reduced rank regression. Result shows that prices are transmitted largely and more rapidly in non-trade periods than the period of physical trade flows. The study by Surathkal, Chung and Han (2014) to investigate the asymmetric adjustments in vertical price transmission in the US beef sector, who testing for differences among product cuts and quality grade. By using threshold-type adjustments to investigate the dynamic link between wholesale and retail prices of beef products. Their findings suggest that decrease or increase in prices of beef will be passed differently to the retailer level based on the quality grades.

This article aims at studying the price dependence of tomato which is highly perishable product. A series of research articles that assess the price transmission for the perishable product found evidence that the price of perishable products transmitted asymmetrically; contradictory results have also been found. Group of studies has found asymmetries in price transmission of perishable products that decrease in prices will be passed more completely than prices increase to the wholesale level, while retailers not respond to decline in prices but respond to price increases (Girapunthong, Van Sickle, and Renwick 2003; Ward 1982; Ahn and Lee 2015). Another group of studies, however, confirms the symmetric price transmission for perishable products (Serra and Goodwin 2003; Santeramo and von Cramon-Taubadel 2016).

The article by Amikuzuno and von Cramon-Taubadel (2012) studies the seasonal variation in price transmission between tomato markets in Ghana; they have assessed the price transmission in tomato supply chain with considering the seasonal variation. The vector ECM with seasonally regime-dependent adjustment parameters to the wholesale level have been applied for this purpose. They have found evidence that tomato markets are integrated and the price transmitted very quickly specially in the time that Burkina Faso offering tomatoes to Ghana. Results also indicate that the seasonal variation in tomato prices is transmitted along the tomato market chain. The work by Ahn and Lee (2015) studies the asymmetric price transmission along the fresh fruits chains at shipping points and terminal markets in the western United States. They have applied autoregressive distributed lag model and the dynamic multiplier effects of the terminal price. The statistical inferences on asymmetry based on Monte Carlo simulations have also investigated. Evidence of asymmetric price transmission is found specially for the more perishability products, and the behaviour of asymmetric price transmission depends on the product perishability degree.

Study by Santeramo and von Cramon-Taubadel (2016) assesses the different interpretations and reasons of the asymmetric price transmission for perishable and non-perishable vegetables and fruits, by using asymmetric vector ECM. They have focused on 14 fresh vegetables and 15 fresh fruits. Results indicate that vertical price transmission is asymmetric for low perishable products, while it tends to be symmetric for more perishable products. The article by Santeramo (2015a) showed, by applied asymmetric threshold autoregressive econometric model, that highly perishable products are more sensitive to market crisis. Results also suggest that tomatoes and cauliflowers in European markets are not efficient; asymmetry in prices transmission has been found in both markets with a quick transmission of price declines in cauliflowers market.

Copula models are the modern methodology used by economists to study the dependence between prices. These approaches 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) assesses the dependence between crude oil and biodiesel blend prices, and crude oil and diesel prices during extreme market events in Spain. They have applied statistical copulas for this purpose. The evidence of asymmetric dependence between crude oil and biodiesel prices have been found, extreme increases in crude oil price not likely to be passed to the consumer level, while increases and decreases in crude oil prices likely to move equally to the diesel prices. The work by Goodwin et al. (2011) studies the joint distribution of North American lumber prices in different markets (Eastern Canada, North Central US, Southeast US, Southwest US). Copula models have been used to study the dependence between prices at the geographical locations considered. Results indicate that market adjustments are generally large in response to large price differences that reflect more substantial disequilibrium conditions.

The unpublished article by Qiu and Goodwin (2013) relies on the application of static and time-varying copula models to the empirical study of the links between farm–retail and retail–wholesale prices for US hog/pork markets. Results indicate that farm and wholesale markets are closely related to each other, while retail price adjustment is less dependent on the other two markets. Wholesale–Retail price adjustments have relatively constant dependence structures. The asymmetric price transmission between farm and retail markets has been found. Increases in farm prices are translated to the retail level, while the price declines are less likely to be passed to consumers. The article by Ahmed and Serra (2015) assesses the correlation between price and yield perils using statistical copula models to determining how the introduction of agricultural revenue insurance contracts in Spain will affect the cost of purchasing insurance. Results indicate that revenue insurance is likely to reduce the price of agricultural insurance in Spain, which may result in higher acceptance and demand for agricultural insurance programmes. The work by Fousekis and Grigoriadis (2016) studies the linkage between different quality coffee beans prices by using nonparametric copula models. The article relies on monthly spot prices from 1990 to 2015. Results indicate that there is strong relationship between the Arabica beans prices, while the dependence is less between the individual prices of Arabica and the Robusta beans. Results also found evidence of symmetric prices transmission.

Our article contributes to the literature by assessing dependence between producer–wholesaler and wholesaler–retailer price levels in tomato markets in Egypt. During the political transition period, Egypt suffered from food insecurity and food price instability. It is thus important to pay special attention to extreme upturns and downturns of the tomato market, as these are likely to have a stronger impact on food security and economic issues. Since we assess a period of important changes, not only static but also time-varying copulas are used in order to allow for changes in price patterns. To our knowledge, this is the first attempt to study vertical price transmission in LCD countries using this methodology.

IV. Methodology

Multidimensional copula functions have used to assess the dependency between prices along the tomato supply chain in Egypt. While copulas have been widely used in the financial economics literature (Patton 2006, 2012; Parra and Koodi 2006), empirical studies that use copulas to assess dependency along the food marketing chain are scarce, even more so in developing economies. Statistical copulas have the advantage of allowing high flexibility when studying correlation between two or more variables. Copulas are based on the Sklar's (1959) theorem that shows how multivariate distribution functions characterizing dependence between n variables, where n is the number of the variables, can be decomposed into n univariate distributions and a copula function, the latter fully capturing the dependence structure between variables. A copula function is a multivariate distribution function defined on the unit cube $[0, 1]^n$; the parenthesis are draw two or more variables with uniformly distributed marginal.

Since our analysis is of a pairwise nature, let F_x and F_y be the univariate distribution functions of two random variables (x, y). $H(x, y)$ is assumed to represent the joint distribution function. According to the Sklar's theorem, there exists a copula $C(.)$ that can be defined as (Embrechts, Lindskog, and McNeil 2001)

$$H(x, y) = C(F_x(x), F_y(y)) = C(u, v) \tag{1}$$

where $C(.)$ is a two-dimensional distribution function with uniformly distributed margins $u : Unif(0, 1)$ and $v : Unif(0, 1)$. The joint density function can be expressed as

$$h(x, y) = f_x(x) f_y(y) c(u, v) \tag{2}$$

where c is the copula density and $f_x(x)$ and $f_y(y)$ are the univariate density functions of the random variables.

Different copula families represent different dependence structures and specifications (see Figure 1 from Patton (2006), which represent the copula models with different standard normal marginal distributions). Analysis of the price linkage by using copula models can study the prices at higher (lower) levels and move together (Reboredo 2011). Our analysis considers both elliptical (Gaussian and Student's t copulas) and Archimedean (Gumbel, Clayton and symmetrized Joe-Clayton [SJC] copulas) copulas. Elliptical copulas are copulas that can study the dependency between two or more variables in central area of the distribution ignoring the distributions in the tails. For such a purpose, we have applied Archimedean copulas to overcome of this limitation (Nelsen 2006; Joe 1997). Archimedean copulas are commonly used to study the dependence between prices, which can assess the prices during extreme market events (downturns and upturns). Gumbel copula is one of the Archimedean copulas that can study the response to positive price shocks more than negative shocks, while Clayton is studying the opposite. SJC copula has upper and lower tails to study the positive and negative price shocks together that can examine the asymmetric dependence between prices (Patton 2006).

Copulas can be categorized as static and time varying. A static copula implies parameter constancy over time, while a time-varying copula allows the parameters to change with changing environment. In order to ensure that the copulas correctly fit our data, a series of time-varying dependence and goodness-of-fit (GoF) tests are conducted. As a result, price dependency along Egyptian tomato marketing chain is modelled using four copulas. The Gaussian copula selected for being the benchmark copula in economics. The Student's t, its dynamic version and the SJC copula are selected based on statistical selection criteria (the log-likelihood value and GoF statistics described below).

The bivariate Gaussian copula can be expressed as

$$C_R^{Ga}(u, v; R_{12}) = \int_{-\infty}^{\Phi^{-1}_{(u)}} \int_{-\infty}^{\Phi^{-1}_{(v)}} \frac{1}{2\pi\sqrt{(1 - R_{12}^2)}} \exp\left\{\frac{-(s^2 - 2R_{12}uv + t^2)}{2(1 - R_{12}^2)}\right\} dsdt \tag{3}$$

where $-1 < R_{12} < 1$ is the correlation coefficient of the corresponding bivariate normal distribution, u and v are random variables, $S = \varphi(U)/[\varphi(U) + \varphi(v)]$ and $T = C(U, V)$, S and T are given by the joint density function $H(s, t) = sKc(t)$ for all (s, t) in $[0, 1]^2$ and Φ denotes the univariate normal distribution function. While the Gaussian copula represents dependence in the central region of the distribution, it assumes non-dependency in the extreme tails of the distribution. The implication for our analysis is that price transmission along the food market chain does not occur for very high/low market prices. A bivariate student's t copula can be expressed as

$$C_{\gamma,R}^{t}(u, v) = \int_{-\infty}^{t_\gamma^{-1}(u)} \int_{-\infty}^{t_\gamma^{-1}(v)} \frac{1}{2\pi\sqrt{(1 - R_{12}^2)}} \exp\left\{1 + \frac{r^2 - 2R_{12}rs + s^2}{\gamma(1 - R_{12}^2)}\right\}^{-(\gamma+2)/2} drds \tag{4}$$

where R_{12} is the correlation coefficient of the corresponding bivariate t-distribution with γ degrees of freedom, and t_γ denotes the bivariate distribution function. The Student's t copula assumes positive and symmetric lower and upper tail dependence.

As noted above, evidence of AVPT within the food marketing chain is abundant. 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 SJC specification. The Joe-Clayton copula can be expressed as

$$C_{\tau^U,\tau^L}^{jc}(u, v) = 1 - \left(1 - \left\{\left[1 - (1 - u)^k\right]^{-\gamma} + \left[1 - (1 - v)^k\right]^{-\gamma} - 1\right\}^{-1/\gamma}\right)^{1/k} \tag{5}$$

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. The Joe-Clayton copula implies asymmetric dependence, even when $\tau^U = \tau^L$. The SJC copula allows

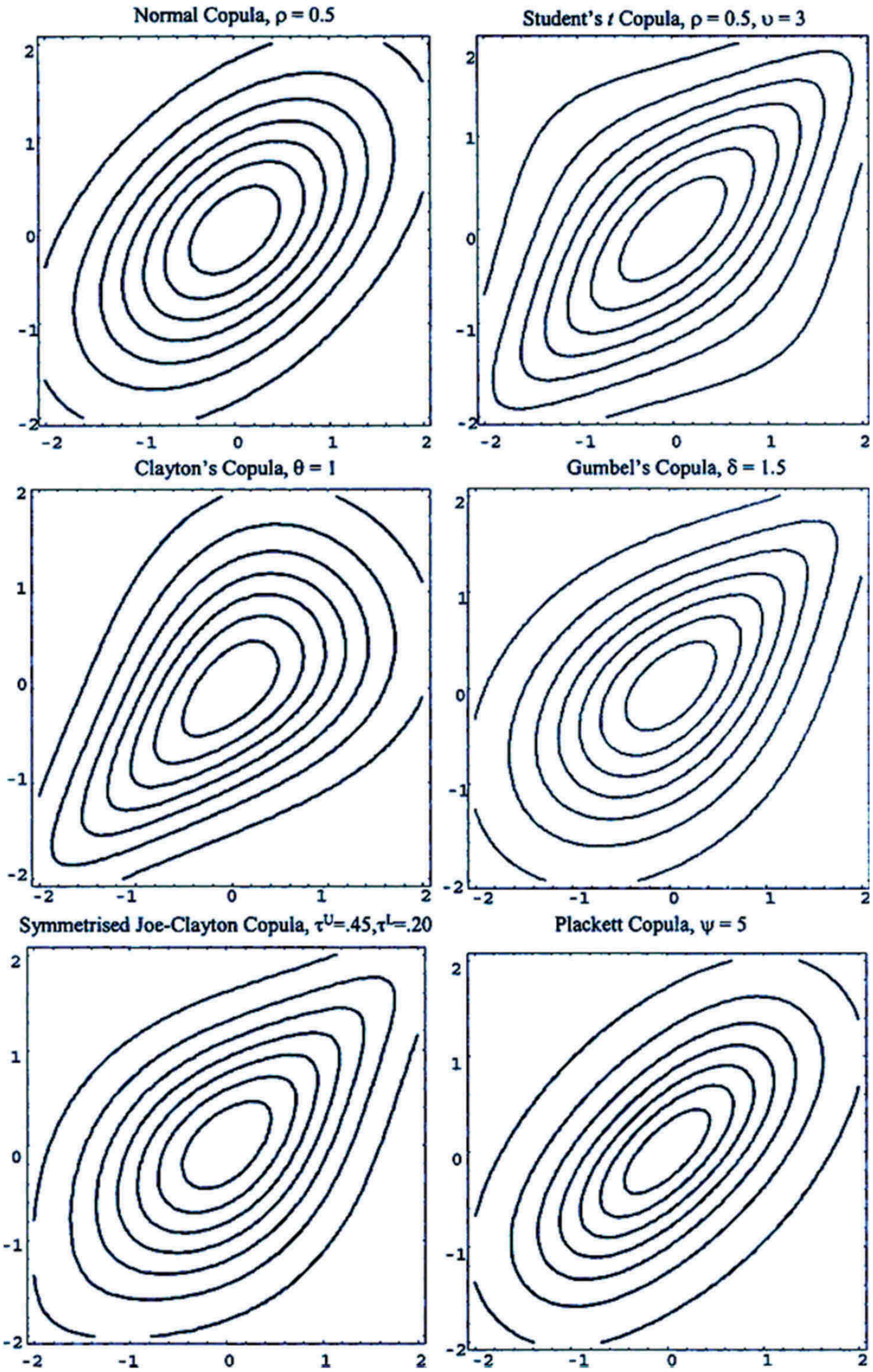

Figure 1. Copulas represent the different dependence structure with linear correlation coefficient of 0.5 (from Patton 2006).

overcoming this problem (Patton 2006) and can be specified as

$$C^{sjc}_{\tau^U,\tau^L}(u,v) = 0.5\left(C^{jc}_{\tau^U,\tau^L}(u,v) + C^{jc}_{\tau^U,\tau^L}(1-u,1-v) + u + v - 1\right) \tag{6}$$

Two types of time-varying dependence tests have used to determine whether time-varying copulas need to be considered (Patton 2013). The first focuses on rank correlation breaks between u and v at some unknown date and has based on the 'sup' test statistic (Patton 2013). The second test is the

ARCH LM test for time-varying volatility (Engle 1982). Both tests provide support for the use of time-varying copulas The dynamic Student's t copula is chosen on the basis of the highest log-likelihood values, to capture dependency changes, and defines the correlation parameter to evolve through time as shown in Equation (7) (Patton 2006):

$$\rho_t = \Lambda\left(\omega_\rho + \beta_\rho \rho_{t-1} + \alpha_\rho \frac{1}{10}\sum_{i=1}^{10} t_\gamma^{-1}(u_{t-i}) t_\gamma^{-1}(v_{t-i})\right) \tag{7}$$

where t_γ^{-1} is the inverse of the t distribution of ε_t with γ degrees of freedom, and $\Lambda = (1+e^{-x})^{-1}$ is the modified logistic function.

Copulas can be estimated through two stage estimation processes. The first stage consists of estimating marginal models that filter information contained in univariate distributions and allow deriving standardized, independent and identically distributed (*i.i.d.*) residuals from the filtration. The copulas have estimated in a second stage either through parametric or non-parametric methods. We use the latter that consist of transforming the *i.i.d.* residuals into $Unif(0,1)$ using the non-parametric empirical cumulative distribution function (EDF). The empirical EDF method is specially convenient when the true distribution of the data not known. The maximum likelihood method has applied on the uniform residuals to estimate copula. Since the theory of copulas applies on stationary time-series, tests for unit roots are run on our data. Results support the absence of a unit root in producer, wholesaler and retailer prices.

Univariate ARMA(p_a,q_a)–GARCH(p_g,q_g) marginal models capture univariate price patterns with p_a representing the number of autoregressive parameters of the ARMA model; q_a the number of moving average components, p_g the number of autoregressive terms in the GARCH specification and q_g the number of lags of squared innovations. Residuals have modelled through GARCH specification in order to allow for time-varying and clustering volatility:

$$P_t = c + \sum_{i=1}^{pa} \eta_{1i} P_{t-i} + \sum_{i=1}^{qa} \eta_{2i}\varepsilon_{t-i} + \varepsilon_t \tag{13}$$

$$\sigma_t^2 = \omega_i + \sum_{i=1}^{pg} \omega_{i2}\sigma_{t-i}^2 + \sum_{i=1}^{qg} \omega_{i1}\varepsilon_{t-i}^2 \tag{14}$$

where P_t are the prices considered, c is the constant of the conditional mean model, η_{1i} is the coefficient representing the autoregressive component, η_{2i} is the coefficient representing the moving average component, being ε_t a normally distributed error term, ω_i is the constant in the conditional volatility model, being ω_{i1} and ω_{i2} the coefficients representing the lagged square residuals and variance, respectively.[4] Log-likelihood methods assuming normally distributed errors have used in model estimation.

Following Patton (2013), GoF tests have used to assess to what extent an estimated copula model is different from the unknown true copula. Comparison of estimated with unknown copula is made through the Kolmogorov–Smirnov (KS) and the Cramer–von-Mises tests (Genest and Rémillard 2008; Genest, Rémillard, and Beaudoin 2009; and Rémillard 2010). Conducting GoF tests on the marginal models is essential for copula model estimation. In order to make sure that the residuals obtained from univariate models have no autocorrelation, the Ljung–Box tests are used. The LM tests of serial independence of the first four moments of u_t and v_t are also used. We also rely on the KS test to make sure that the transformed series are $Unif(0,1)$ (see Patton 2006 for further details).

V. Empirical analysis

The analysis is based on weekly producer, wholesaler and retailer tomato price data, expressed in Egyptian pound/kg, and observed from the first week of April 2011 to the last week of March 2014, leading a total of 155 observations (see Figure 2). The three series have obtained from the Egyptian cabinet information and decision support centre (IDSC 2014). Standard unit root tests show that the series are stationary (Table 2). Table 3 presents summary statistics for price series. These statistics provide evidence of non-normal price series, characterized by skewness, kurtosis and ARCH effects.

Results from univariate ARMA–GARCH model, whose specification is chosen through the Akaike's information criterion and Bayesian information criterion of Schwarz's, are presented in Table 4. An ARMA

[4]The univariate model was specified according to parsimony and statistical significance.

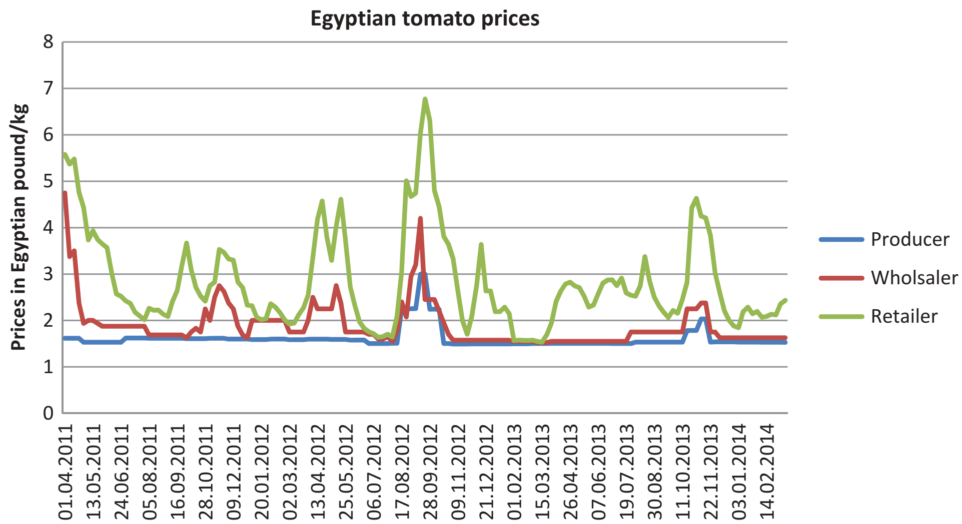

Figure 2. Price series used in the analysis (weekly producer, wholesaler and retailer tomato price data) expressed in Egyptian pound/kg and observed from the first week of April 2011 to the last week of March 2014.

Table 2. Unit root tests for producer, wholesaler and retailer tomato price series.

	t-Test	Critical values: 1%	Critical values: 5%	Critical values: 10%
Dickey–Fuller (Dickey and Fuller, 1979) test for unit root				
With intercept				
Producer prices	−3.834	−3.474	−2.880	−2.577
Wholesaler prices	−4.898	−3.474	−2.880	−2.577
Retailer prices	−4.573	−3.474	−2.880	−2.577
Augmented Dickey–Fuller (Dickey and Fuller, 1979)test for unit root				
With intercept				
Producer prices	−5.177	−3.460	−2.880	−2.570
Wholesaler prices	−7.051	−3.460	−2.880	−2.570
Retailer prices	−4.574	−3.460	−2.880	−2.570

Table 3. Summary statistics for producer, wholesaler and retailer tomato prices expressed in Egyptian pound/kg.

	Producer prices	Wholesaler prices	Retailer prices
Mean	1.609	1.887	2.820
SD	0.018	0.038	0.083
T-statistic	88.295	49.643	33.909
Skewness	4.050*	3.023*	1.413*
Kurtosis (excess)	18.764*	12.386*	1.909*
Anderson–Darling test	28.386*	13.091*	6.383*
ARCH LM test	38.300*	14.615*	62.980*
Number of observations	155	155	155

*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 Anderson–Darling is the well-known test for normality. The ARCH LM test of Engle (1982) is conducted using 10 lags.

Table 4. Univariate ARIMA–GARCH model for producer, wholesaler and retailer tomato prices.

Variable	Producer prices	Wholesaler prices	Retailer prices
Conditional mean			
C	0.609**	0.681**	0.126**
	(0.161)	(0.138)	(0.048)
ϕ_1	0.621**	0.629**	1.781**
	(0.099)	(0.071)	(0.059)
ϕ_2			−0.826**
			(0.051)
θ_1	0.291**	0.046**	−0.574**
	(0.106)	(0.098)	(0.095)
θ_2	0.054	0.232**	−0.296**
	(0.085)	(0.087)	(0.089)
θ_3	0.440**	0.067**	
	(0.078)	(0.084)	
θ_4	0.380**	0.282**	
	(0.088)	(0.081)	
Conditional variance			
ω_i	0.002**	0.005**	0.041**
	(2.509e − 07)	(1.439e − 06)	(0.001)
ω_{i1}	0.325**	0.413**	0.437
	(0.026)	(0.017)	(0.031)
ω_{i2}	0.582**	0.554**	0.329**
	(0.009)	(0.004)	(0.016)
Ljung–Box *Q*(10)	8.929	11.199	7.759

(**)Denotes statistical significance at the 10% (5%) level.

(1,4)–GARCH(1,1) model is fit to producer and wholesaler prices, while an ARMA(2,2)–GARCH(1,1) better represents retailer prices. Conditional mean model results suggest that current price levels have positively influenced by price levels during the last week. Uunivariate GARCH (1,1) model parameter estimates are all positive for the three prices considered, which indicates that past market shocks as well as past volatility bring higher current volatility levels. Since $\omega_{i1} + \omega_{i2} < 1$, we can conclude that the three GARCH processes are stationary, being the unconditional long-run variance $\sigma_i^2 = \omega_i/(1 - \omega_{i1} - \omega_{i2})$ around 0.022, 0.143 and 0.176 for producer, wholesaler and retailer prices, respectively. Hence, in the Egyptian tomato market, consumer prices have long-run volatilities that are above the volatilities at the producer and wholesale price level.

The Ljung–Box test results presented in Table 4 fail to reject the null of no autocorrelated residuals. The LM tests (Table 5) for the independence of the first four moments of the transformed variables provide evidence that the models are well specified. The KS test confirms that the transformed series are *Unif* (0,1) (Patton 2006). Time-varying dependence tests in Table 6 support the use of time-varying copulas. In Table 7, we present the log-likelihood values for a wide range of copulas. Those copulas yielding the highest log-likelihood (Gumbel, Student-*t*, SJC, time-varying SJC and Student's *t*) values are selected for a more in-depth analysis. The Gaussian copula is also chosen as the benchmark model in economics.

Results of KS_C and CvM_C GoF tests (presented in Table 8) for producer–wholesaler pair of prices suggest the Student's *t* constant copula as the one providing the best fit, being the second best fit provided by the Gaussian and the SJC constant copulas. In the wholesaler–retailer case, the SJC constant copula offers the first best fit and Student's *t* constant copula the second best. For time-varying copulas, the GoF tests suggest that the Student's *t* better fits the data relative to SJC copula for both pairs of prices. Given these results, static Gaussian, static and dynamic Student's *t* and static SJC copulas are considered in our analysis. Static copula results are presented in Table 9 and dynamic copula findings in Table 10.

Results of Gaussian and Student's *t* copula presented in Table 9 imply a positive short-run correlation between prices at different market levels. The association is stronger between producer and wholesale prices than between wholesale and retail prices. Furthermore, the inverse of the degrees of freedom of Student's *t* copulas is 0.170 and 0.216 for producer–wholesaler and wholesaler–retailer pairs of prices, respectively.

Table 5. LM tests on the transformed prices (u_t and v_t).

	Producer prices	Wholesaler prices	Retailer prices
First moment LM test	0.869	0.627	0.784
Second moment LM test	0.984	0.627	0.912
Third moment LM test	0.997	0.767	0.966
Fourth moment LM test	0.880	0.862	0.982
K–S test	0.317	0.318	0.531

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.

Table 6. Time-varying rank correlation between prices.

		AR(*p*)		
Price pair	Break occurring anywhere	1	5	10
Producer–wholesale	0.002	0.001	0	0.008
Wholesale–retail	0.003	0.002	0	0.008

This table presents *p*-values from one-time break correlations and autocorrelation (AR) tests for time-varying dependence using 1000 bootstrap replications. The left panel test focuses on rank correlation breaks between *u* and *v* at some unknown date. The right panel is the ARCH LM test for time-varying volatility proposed by Engle (1982) that focuses on autocorrelation in dependence.

Table 7. Log likelihood values for static copulas.

	Producer–wholesaler	Wholesaler–retailer
	Log likelihood	*Log likelihood*
Gaussian	12.151	3.363
Clayton	8.217	1.774
Rotated Clayton	12.966	4.726
Plackett	11.034	2.726
Frank	10.792	2.426
Gumbel	13.659	4.822
Rotated Gumbel	11.265	2.938
Student's *t*	13.431	4.919
Symmetrized Joe Clayton	14.662	4.919

Table 8. Goodness-of-fit tests for copula models.

	KS_C	CvM_C	KS_R	CvM_R
Producer–wholesaler				
Gaussian	0.120	0.030		
Gumbel	0.020	0.050		
SJC	0.030	0.110		
Student's *t*	0.120	0.130		
Time-varying SJC			0.820	0.360
Time-varying Student's *t*			0.880	0.430
Wholesaler–retailer				
Gaussian	0.190	0.410		
Gumbel	0.050	0.220		
SJC	0.300	0.590		
Student's *t*	0.200	0.470		
Time-varying SJC			0.180	0.150
Time-varying Student's *t*			0.320	0.460

This table presents *p*-values from goodness-of-fit tests for four different copula models using 100 bootstrap replications. KS_C and CvM_C tests refer to the Kolmogorov–Smirnov and Cramer–von Misses tests, respectively, applied to the empirical copula of the standardized residuals. KS_R and CvM_R tests refer to the Kolmogorov–Smirnov and Cramer–von Misses tests, respectively, applied to the empirical copula of the Rosenblatt (1952) transform of these residuals.

Table 9. Results from static copulas.

Producer–wholesaler		
Gaussian		0.381**
		(0.074)
Log likelihood		12.151
SJC(τ^L, τ^U)	0.141**	0.297**
	(0.081)	(0.095)
Log likelihood		14.662
Student's *t* (ρ, v^{-1})	0.388**	0.170**
	(0.071)	(0.101)
Log likelihood		13.431
Wholesaler–retailer		
Gaussian		0.206**
		(0.087)
Log likelihood		3.363
SJC(τ^L, τ^U)	0.002	0.174**
	(0.002)	(0.089)
Log likelihood		4.919
Student's t (ρ, v^{-1})	0.191**	0.216**
	(0.091)	(0.108)
Log likelihood		4.919

(**)Denotes statistical significance at the 10% (5%) level.

Table 10. Time-varying Student's t copula.

		Producer–wholesaler	Wholesaler–retailer
Student's t	$\hat{\omega}$	0.056	0.459**
		(0.042)	(0.105)
	$\hat{\alpha}$	0.190**	0.446**
		(0.043)	(0.155)
	$\hat{\beta}$	0.950**	0.102**
		(0.026)	(0.179)
	γ^{-1}	0.213**	0.168**
		(0.063)	(0.129)
Log likelihood		18.651	6.598

(**)Denotes statistical significance at the 10% (5%) level.

This implies strong dependence in the tail, which is not captured by the Gaussian copula. It is thus relevant to estimate a copula that allows for dependency for very high/low market prices.

Results of SJC copulas provide support for asymmetric dependency during extreme market events. The SJC copula for the producer–wholesaler price pair shows stronger (52% higher) upper than lower tail dependency, which suggests that price increases tend to be passed from producers to wholesalers more completely than price declines. For the wholesaler–retailer price pair, the lower tail is not statically different from zero. Conversely, the upper tail is statistically significant and on the order of 0.17, which implies that while price increases will be transferred from wholesalers to retailers, price declines will be not. Hence, retailers are more likely to increase prices than to reduce them, which reflects the degree of market power that retail chains have in Egypt.

Time-varying Student's t copula shows how dependency among the pairs of prices considered changes over time. Estimation results are presented in Table 10 and graphed in Figure 3 for the producer–wholesaler price pair, indicating that dependence from April 2011 to March 2013 was relatively low and fluctuated around 0.4. In the period from March 2013 to December 2013, dependence increased reaching values around 0.8. Such increase is likely to be related to the GDA project involving USAID, ACDI-VOCA, Heinz International and 13 domestic tomato processors. The aim of this partnership was to increase trust between producers and tomato processors that stabilize their relationships through forward contracts; such relationship leads to increase the dependency between the producer and wholesaler. Time-varying Student's t tail dependence displayed in Figure 4 shows a low dependency between wholesaler and retailer market levels, which is on the order of 0.2 that fluctuates over the period studied, mainly in the range from 0 to 0.4. Low dependency between wholesaler and retailer prices may be explained by retailers' market power and a lack of forward contracts linking these two levels of the marketing chain. Fluctuations are not surprising given the economically tumultuous period studied.

In general, tomatoes as perishable product need to be sold quickly to the wholesaler, traders and/or tomatoes processor companies, involved the GDA project in tomato market in Egypt given the opportunity to the tomato farmers to sale 30% of the production to the tomato processors. That led to increase the dependency between producer and wholesaler; increases and decreases in producer prices will be passed to the wholesale level, but price rising will be passed more completely than falling prices, while the wholesalers do not have other outlets to sale their tomatoes except retailers. The increase in tomato prices will be passed to retail level, while the declines will not be transferred. This result is matched to Ward's (1982) result that retailers exert their market power to prevent prices declines from passing through the wholesaler to retail level. In developing countries, retailers' market power in food supply chains is not surprising where there is lack of the competitiveness, information and forward contracts.

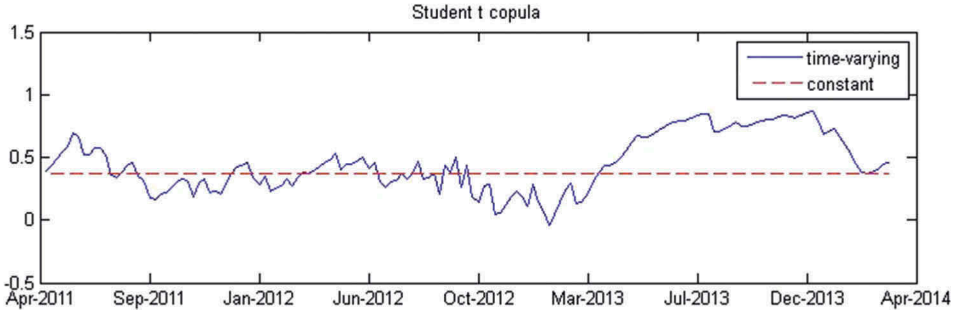

Figure 3. Time varying student t copula for producer–wholesaler price pair.

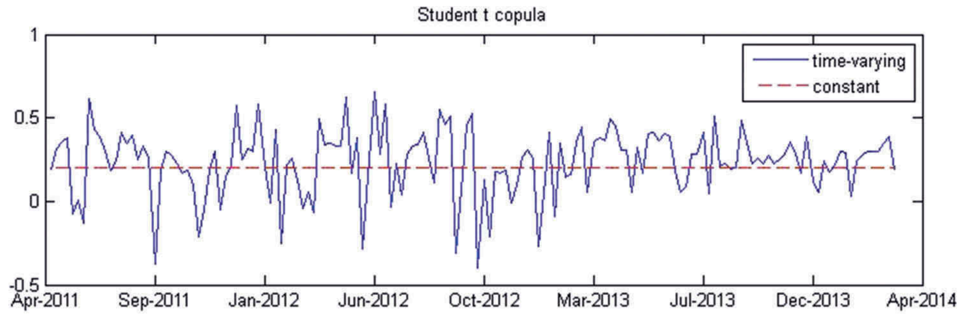

Figure 4. Time varying student *t* copula for wholesaler–retailer price pair.

VI. Concluding remarks

Food price analyses along the food chain have started to gain relevance in developing economies as data are becoming available. These analyses are of high political, social and economic interest, specially in light of low-income levels and chronic poverty affecting these countries. Egypt suffers from high food prices since the food price crisis in 2007/2008. The revolution of 25 January 2011 came to accentuate price increases.

Our analysis focuses on tomato prices dependency along the Egyptian supply chain. To do so, we use flexible methods that do not require assumption of restrictive multivariate distribution functional forms. In this context, we apply static and time-varying statistical copulas to assess co-movements between two pairs of prices: producer–wholesaler and wholesaler–retailer prices, both in the central and in the extreme regions of the distribution. Results for the producer–wholesaler price pair involve positive dependence in the central region of the distribution. Further, extreme increases in tomato producer price will be passed on to wholesaler price more completely than producer price declines. Results from wholesaler–retailer price model also show a positive dependence in the central region of the bivariate distribution, though less strong than the one for the producer–wholesale price pair.

Regarding dependency during extreme market events, asymmetric dependence has been found by which extreme increases in wholesale prices are passed on to retailer prices, while declines are not. As a result, food consumers will not be benefited from extreme declines in prices at upper levels of the food chain, but they will have to endure extreme price increases. Entering the project of GDA into the tomato market in Egypt aims to strengthen the relation between farmers and tomato processors through forward contracts. Under forward contracts, the tomato farmers find other outlets rather than fighting with wholesalers, which increase the dependency reaching, sometimes, around 0.8. The lack of the forward contracts between wholesalers–retailers allows retailers to exercise market power that prohibits the prices decline to be passed, while allows passing the price increases. These results are consistent with Kinnucan and Forker (1987), Sexton, Zhang and Chalfant (2003), Ahn and Lee (2015) and Aguiar and Santana (2002). Their findings suggest that prices are transmitted asymmetrically for perishable products. While in contrast of some studies such as Serra and Goodwin (2003), Santeramo and von Cramon-Taubadel (2016), they find evidence of symmetric price transmission for more perishable products.

Policies, such as provision of inputs at subsidized prices, or the promotion of adoption of technological advances in the production of tomatoes, may imply reduce production costs. Due to the presence of asymmetries, it is not however warranted that this decline in costs will be transferred down the marketing chain until reaching consumers; such policy may help for non-perishable products that could not be affected by asymmetries in the price transmission. In order to combat food insecurity in a country where famine is worrisome, further actions down the marketing chain are required in order to increase the competitive behaviour of this chain and facilitate smooth price transmission. The lack of competitive behaviour in the nexus wholesaler–retailer levels is evidenced by a lower degree of dependency between these two market levels. The partnership between government and private sectors could help to increase the competitive behaviour in the tomato market, by the execution of forward contracts to have more transparency in such markets and fair fights between producer–wholesaler and wholesaler–retailer that lead to prices transmit smoothly along the tomato supply chain, which could also keep the tomato prices lower at retail level to protect consumers against significant price increases.

One of the tomato characteristics is the seasonality. The limitation of present analysis is that the seasonality variation did not take into the consideration. Study the seasonality variation in price transmission for perishable products by using dependence models would be desirable and could be considered in the future studies. The estimation for further models could be supplemented in the present estimation results such as vine copula models, Markov-switching GARCH and regime-dependent adjustment speeds.

Disclosure statement

No potential conflict of interest was reported by the author.

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