A contribution to the empirics of food price behavior: the case of rice price dynamics in Italy

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Abstract

Purpose – The purpose is to detect the nonlinearity wholesale rice price formation process in Italy in the 1995–2017 period.

Design/methodology/approach – A nonlinear smooth transition autoregressive (STAR)-type dynamics model is used.

Findings – Wholesale rice prices are significantly affected by variations in the international price of rice as well as variations in Arborio price.

Research limitations/implications – The limitations include policy recommendations for the production and commercialization of rice in Italy.

Practical implications – Understanding rice pricing dynamics and nonlinearity behavior is pivotal for the survival of the entire European and Italian rice supply chain.

Originality/value – In the extant literature, no evidence exists on non-linearity of rice prices in Italy.

Keywords Rice market, Smooth transition autoregressive (STAR) approach, Italy, Nonlinear price dynamic

Paper type Research paper

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1. Introduction

Food security is a fundamental issue for humanity. The current global economic conditions as they relate to the changes brought about by the COVID-19 pandemic introduce significant uncertainty that one way or another will be manifested in price changes and behavior. In this regard, rice plays an essential role as it is the most important and diffused staple crops in the world. Rice (*Oryza sativa L.*) represents almost one-fifth of total crops area harvested, one-fifth of all caloric intake from food staples, and nearly one-half of all food expenditures among poor people living in low- and middle-income countries (Dawe *et al.*, 2010). In Europe, Italy plays a primary role as the main producer of the Japonica type of rice. Japonica is best associated with Risotto! Rice price, as many commodity prices do, displays a significant level of variation across time and rice varieties. Predicting the nature, magnitude and direction of these variations has large economic implications. Thus, understanding the inherent and deterministic price dynamics is a relevant research topic and the center focus of this study. Here, we pay particular attention to study price dynamics for the Japonica rice variety mainly grown in the Northern Padana Plateau Region in Italy.

Let us first consider that both production and consumption of rice have increased considerably in the last decades. For instance, when looking at the 2016/2017 (growing/harvest) season rice data we can observe that worldwide consumption reached about 475.64 million metric tons while per capita global rice consumption was about 54.24 kg. By the same token, total world harvested area is approximately 158 million hectares, with yields oscillating between 1 ton per hectare in poor rain-fed conditions, and more than 10 tons per hectare in countries with tempered conditions and modern irrigation systems. Rice varieties are divided between Japonica and Indica. Indica is primarily produced in Asia (China and India are the main producers followed by Indonesia, Bangladesh, Vietnam, Myanmar and Thailand) [1], and it is the predominant variety in the international markets. Japonica, on the other hand, is regional-specific and mainly produced in Europe. Italy is the main producer of Japonica, representing about 1% of total world rice production. Due to its characteristics, Japonica rice is particularly suitable for Mediterranean dishes and recipes, specifically Risotto – a typical and traditional Italian dish – and Paella – a typical Spanish dish. Incidentally, Japonica differentiates from Indica, both because of its higher quality and concomitant price. By the same token, there are multiple varieties, all encompassed within the Japonica family; where the best-known are Arborio and Carnaroli.

The relevance of rice as a staple in the diet of a large segment of the world population is represented by the more than three times fold increased production during the 1960–2010 period (FAO, 2017). In this context, data from 2017 indicates that total paddy production was about 756.7 million tons (FAO, RMM, December 2017). However, despite the impressive increase in world production, a faster/larger increase in world consumption has created a significant imbalance between supply and demand. This imbalance results in an upward effect on price dynamics at the global level and higher price variability, with marked consequent direct influences in local markets (Haile *et al.*, 2015). It is paramount to understand that variations in rice price have significant economic impacts on a large segment of the world population and thus understanding price variations and more relevant the presence of asymmetric and nonlinear behavior is a relevant and timely research topic.

As noted earlier, the literature documents that price variations have direct consequences on food security and quality of life for large segments of population. In addition, the effect of price variability extends directly to socioeconomic growth and political stability of the growing region, and in general to the producing country. From a historical perspective, take for instance the 2007/2008 food crisis where staple food prices increased in excess of 50%. The negative social and welfare effects on those already spending a significant proportion of their income of food items was large and extensive. However, it is as well relevant to consider that price increases in the presence of such events have also been accompanied with higher price volatility, making the presence of asymmetric behavior evident. For instance, in periods of food crisis (such as 2007–2008, 2011 and 2012) to ameliorate negative effects of above average price increases, governments were prompt to adopt and implement policy adjustments to protect their domestic market, as well as limit and/or reduce possible negative effects that price shocks may have on local producers and consumers. From the academic and policymaking perspectives, knowing and understanding the sources of price variation are of fundamental importance in commodity markets such as rice. With increase variability, accurately being able to understand and possible predict price transition dynamics to long-run equilibrium is therefore a fundamental topic of interest for researchers, with significant implications for policymakers.

As noted, because of its relevance and fundamental role in the daily lives of a large segment of the population, rice price stability becomes an important and timely objective for academic research useful for optimal government policy design. In the case of interest of this paper, the reality of the dynamics of the domestic price of rice determination are such that they are also subject to variations deriving from other sources of shocks, primarily but not limited to movement in the international rice market. We hence bring forth the argument that price transmission effects could be present and significant from Indica to Japonica; especially in the presence of low barriers to trade. There is also the possibility that a proportion, maybe significant, of the exogenous price transmission effects may be determined in an endogenous fashion among different varieties of rice within the same market. In fact, we hypothesize that endogenous price variations within the Japonica varieties could be significant drivers of price formation as well. That is the presence of price co-movement within the Italian market. To test this alternative hypothesis, we also propose to select an Indica variety of rice as the driver of the possible transferring mechanism. In this regard, our initial selection points to Arborio as the main driver.

In this context, our paper focuses on the interesting and relevant questions of, first whether this relationship manifests itself in a linear or nonlinear fashion, and second whether these variations are symmetric or asymmetric in nature (Pede *et al.*, 2018). Because of this dichotomy, it is clear that the implications of these two possible scenarios are large, relevant and most likely very diverse. Consequently, we can safely argue that in the presence of external shocks the transmission effects become relevant in terms of farmland allocation decisions, product commercialization and consumption, and the overall price level. In the case of interest of this study, Italy, this is even more so, given that the EU holds a no-tariff policy in terms of rice imports from developing countries. In this context, we hypothesize that variations in the international benchmark price – approximated by the Thai 5% – are transmitted without barriers and become fundamental determinants of rice production and prices in Italy, possibly in a nonlinear fashion. It is also relevant to contemplate that the dynamics of rice production and price determination may also be affected by path and state dependent events. To illustrate these possible state dependent events, international market fluctuations in rice price may be the result of exogenous variations in weather patterns, and transmitting through international prices. More specifically, these weather oscillations, namely ENSO phenomena in the form of droughts (El Niño) and excessive rain and flooding (La Niña), may have large asymmetric effects on international rice price, leading indirectly to sizable changes in rice price in Italy as well. While the dramatic oscillations in weather (Niño and Niña) are not directly observable in Italy, the transmission effect may be passed down through duty-free imports of Indica rice, and the concomitant price of Thai 5%.

The main purpose of this paper is to investigate the potential inherent nonlinearities in wholesale rice prices in Italy. The use of the Teräsvirta's Smooth Transition Autoregressive (STAR) model is here proposed to study the inherent price dynamics of Japonica rice, and investigate the relationship between Indica price variations and Japonica price. We organized the rest of the paper as follows. Section 2 gives an overview of the principal theoretical streams on nonlinear price movement and transmission literature; as well as a brief yet comprehensive description of the Italian rice market. Section 3 outlines the research design and methods, providing details on the STAR approach adopted and possible nonlinear models. In Section 4 the empirical evidence is analyzed, while the last section contains the conclusions and recommendations.

2. Literature review

Price behavior of food and agricultural commodities has received significant attention in the extant literature. On the one hand, there is much consensus that oscillations of commodities prices is commonly accepted in pricing theory (see Ubilava and Holt, 2013; Roll, 1984 for instance); however, a less agreed upon issue is whether these oscillations follow linear or nonlinear patterns. Recently, the literature has given special attention to potential price nonlinearities (Roll, 1984; Boudoukh *et al.*, 2007; Pede *et al.*, 2018). To better understand price dynamics behavior, evidence on nonlinear dynamics has been associated with the degree of adjustment from one price regime to another; that is the transition patterns that characterize price behavior. In general, the theory argues that first prices may adjust in different fashions to upward than downward changes and secondly prices may adjust differently when changes are close to the mean compared to changes occurring at larger degrees of variance. Understanding these relationships and the differences that each implies can be useful for policy-making purposes when attempting to recover information on structural change in prices. For instance, in a recent study, Pede *et al.* (2018) study rice prices in the Philippines and find strong evidence in favor of the nonlinearity hypothesis.

A particular useful modelling technique to test for nonlinearity is the STAR model. In previous studies such as, Holt and Craig (2006), they use a STAR model on prices of hogs relative to corn in the US and find evidence of nonlinearity and regime-dependent behavior. Similarly Ubilava (2012) study nonlinearities in the US soybean-to-corn price ratio and find evidence in favor of asymmetries in the co-movement of corn and soybean prices. In a related study, using single commodity price dynamics, Reitz and Westerhoff (2006) find that heterogeneous agents and their nonlinear trading impact may be responsible for pronounced swings in commodity prices.

A particular and relevant component of the literature deals with regime switching given its importance to the nonlinearities in commodity prices as a relevant topic in relation to the price transmission along the food chain (Hassouneh *et al.*, 2010). For instance, Goodwin and Holt (1999) argue that transmission of shocks appears to be largely unidirectional with information flowing up the marketing channel from farm to wholesale to retail markets. In the case of wheat, another relevant world staple, Mainardi (2001) applied a threshold and smooth transition co-integration model and found that nonlinear co-integration models have substantial explanatory power for wheat prices. The commonality in these models, is the possibility to determine whether prices exhibit nonlinear behavior conditional on the state of nature and the direction of shocks. Furthermore, these studies demonstrate that the use of simple and whimsical linear modelling is not statistically efficient to detect inherent nonlinear properties of commodity prices.

In regards to rice, Pede *et al.* (2018) provide evidence to indicate that other sources of shocks affect rice productivity and consequently its price dynamics. According to the literature these sources include, primarily, the changing relationship between supply and demand in international rice markets, weather conditions and climate variability with rainfall, draughts and temperature shifts (Ropelewski and Halpert, 1996; Alberto *et al.*, 2012; Lyon and Camargo, 2008); the local policy adjustments with consequences in the long run at international and global stage (Also Gouel, 2013). The consequences on food access and security (Debnath *et al.*, 2018), land use allocation, sociopolitical balance and economic growth perspectives (Santeramo *et al.*, 2018) are direct derivations resulting from the oscillation of prices and their patterns toward the mean reversion behavior that the literature finds as well. More relevantly, in the following studies Holt and Craig (2006); Holt and Balagtas (2009); and Ubilava and Holt (2013) provide robust evidence addressing the importance of using nonlinear estimation methods to model commodity price dynamics. As such we also ground our research estimations making use of the Teräsvirta's Smooth Transition Autoregressive (STAR) model as we further develop in the next section.

The literature also indicates the presence of market intervention techniques aimed at reducing price variations, including but are not limited to, commodity storage and stockpiling, price controls, trade restrictions and policy adjustments to name a few (Shively, (1996); Yao *et al.* (2007)). All these instruments, used independently or jointly have as primary goal to bring price stability around the mean; that is achieve mean reversion behavior faster on prices to a preset or desirable level (Arnade *et al.*, 2017; von Braun *et al.*, 2014). In turn, the achieved objective is to reduce uncertainty that small landholders may encounter (Santeramo *et al.*, 2018) as price variation drift away from expected (sometimes historical) mean values. However, the use of such techniques as intervention for the sake of intervention is not enough if the source, nature and conditionality of price variation behavior fails to account for asymmetric and nonlinear price variations away from the mean. That is the intervention may exacerbate the asymmetry observed in prices. The lack of empirical evidence in studying the presence, existence and type of nonlinearity behavior in commodity prices creates the necessity to provide further evidence of its existence and prevalence. Particularly, recent evidence in support to nonlinear price behavior questions the efficacy of previous policy intervention mechanisms (Pede *et al.*, 2018). A clear example in support of the nonlinearity issues in commodity prices, was also presented by Shively (1996), who notes that markets are incapable of carrying negative inventories. In such cases, imports are used to bridge the gap. Increased imports also bring additional variation and oscillations on domestic prices either through competition or substitution effects.

As research efforts progress to study determinants of price variability, studying the relationship between commodity price dynamics and climate variability became relevant as well. In this field, Ropelewski and Halpert (1996) studied the terms of precipitation patterns in Southeast Asia, while Alberto *et al.* (2012); Lyon *et al.* (2006); and Lyon and Camargo (2008) studied the specific case of the Philippines. More specifically, Roberts *et al.* (2009) report robust evidence indicating that rice yields are negatively affected by weather events, both in irrigated and rain-fed ecosystems. Consequently, and because of its relevance, a large body of work investigates the causes and estimation of asymmetric price transmission (see for instance Ward, 1982; Kinnucan and Forker, 1987; Boyd and Brorsen, 1988; Griffith and Piggott, 1994; Zhang *et al.*, 1995; Bernard and Willett, 1996; Hassouneh *et al.*, 2012; Von Cramon-Taubadel, 1998; Worth, 1999; Parrott *et al.*, 2001; Romain *et al.*, 2002; Girapunthong *et al.*, 2003; Frey and Manera, 2007; Vavra *et al.*, 2005 among others).

So far, the review of the empirical evidence from the extant literature indicates that while some research has been conducted on the nonlinearity of prices, mainly for rice producers in Asia, little to no evidence exists for European countries. This is particularly truer for the case of Italy. In fact, to the best of our knowledge, this paper is the first to provide a study of the possible nonlinearity behavior of rice prices in Italy. Thus, we argue that possible nonlinear price movements are a relevant field of study. In light of the current discussion, understanding rice pricing mechanism is pivotal for the future of the comprehensive European and Italian rice production sector. It is hence crucial to understand the effects of the price dynamics from the main exporting countries of Indica type in relation to pricing of Japonica rice in Italy as well. We believe that our results would be useful and more relevant under the recent developments of the European Agricultural Policy. Consequently, one of our objectives is to provide further and robust modelling and gather empirical evidence to test:

H1. There exist dynamic nonlinearity price movements in the Italian rice prices.

H2. There exist nonlinear dynamic relationships between Japonica rice prices in Italy and the exogenous international price, as approximated by the price of Thai 5% rice.

We further expand the empirical analysis and introduce variations in the price of the Arborio variety as an alternative exogenous shock variable for all other rice varieties included in the analysis.

H3. Variations in the price of Arborio rice have a nonlinear effect on the price of other Japonica types of rice.

A few explanatory words regarding the production and consumption conditions of rice in Europe and particularly in Italy are necessary at this point. In Europe the total rice production in 2016 was 1.8 million tons (+1% compared to 2015), compared to 1.8 million tons of imports (+10% compared to 2015) with a stock of 0.6 million tons. Because of land allocation constraints, production has remained stable over the last few years. However, rice consumption in Europe increased from 2.3 million to 2.8 million tons from 2005 to 2016. Forecast for 2026 reaches 3.0 million tons, representing an increase of 7.14% in the period 2016–2026 (European Commission, 2016). The demand increase together with a stable supply capacity are pushing European countries to increase imports of Indica rice, creating a substitution effect and consequent increased competition among rice varieties.

In this changing scenario, it is also relevant to note that Italy is the largest rice producer in Europe, covering 60% of total production. Italy stands out for its cultivation technique, its technological profile and its ability to adapt in a few decades to different ways of cultivation and harvesting (passing from manual systems to mechanization). In addition, Italy stands as a leader in environmentally friendly technics of production benefiting from its natural location advantages as they relate to a naturally flat territory, well-exposed to the sun, and with stable climate conditions; particularly a secure access to irrigation canals provide optimal conditions for rice production. This combination of elements results on high and consistent quality of Italian Japonica rice. In general, Italian rice has a higher degree of differentiation carrying higher selling prices compared to the foreign alternatives. For example, Arborio has a market price of €700–800/ton compared to the European price of €627/ton for paddy rice and to the average world price of €378/ton (European Commission, 2016).

The Italian rice producers are predominantly of small-medium size with an average cultivated area of 18 hectares and an average yield of 68 quintals/hectare. Only few large companies have land holdings over 300 hectares. Although the performance of Italian rice farms is good, their production capacity is hardly comparable to that of players like the United States of America or new entrants in Asia who have much larger cultivation land. In Italy rice production is concentrated in Northern Po Valley covering the provinces of Pavia, Novara and Vercelli. Geographical location and competition constraints derived from other crops conditions rice production expansion. In this context, there are limited new cultivating areas for rice as well as agronomic constraints dictated by the limit capabilities of crop rotation. Consequently, to meet an increasing demand a concomitant pressure for increased imports has followed. For instance, in the period September 1, 2017–May 15, 2018, Italy imported 63,960 tons of milled rice (paddy rice) of which 62,346 tons were Indica and 1,614 tons Japonica. In the 2016/2017 harvest season production levels were lower, resulting in higher total imports of 62,569 tons, of which 59,444 tons of Indica and 3,125 tons of Japonica (Ente Nazionale Risi, based on data from the Ministry of Economic Development, 2018).

In Italy, production of Japonica rice plays an important role in the economic conditions and cultural practices in the Northern Padana plateau. On the one hand it supports the lives of farmers and on the other it provides a sustained source of food to consumers. More recently, Indica rice has been introduced as a possible substitute crop, as farmers increase rice production diversification strategies to meet demand driven variations. Understanding the nature, variation and relation of rice prices is therefore a relevant and timely research topic. This is particularly more important if rice price variations behave in a nonlinear fashion, and with asymmetric behavior in the up versus down market oscillations.

Thus, based on the review of the extant literature in combination with the current and forecast production and consumption conditions, it is argued that possible nonlinear price movements are a relevant field of study. Consequently, our aim is to provide an empirical contribution to the field by gathering evidence to test aforementioned hypotheses of dynamic nonlinearity price movements in the Italian rice prices and its possible relationship with the international price of Thai 5% rice. The empirical analysis also introduces Arborio price variations as an alternative exogenous shock variable for all other rice varieties included in the analysis. With these considerations, the paper elaborates the model section and provides a description of the data collected for the monthly wholesale price of rice for a comprehensive set of Japonica rice types. In this regard, to the best of our knowledge our dataset is the most comprehensive set available.

3. Data, methods and model specification

3.1 The STAR approach

To theoretical underpinning for the proposed model selection is based on the need to uncover the true relationship of price dynamics within the time-series conceptualization. This section will explain both the data collected as well as the most appropriate method to find the presence of nonlinear behavior instead of the typical assumed linearity of data. In this paper we thus assume – as in Terasvirta and Anderson (1992) – that if the rice price time-series are nonlinear, then it is very plausible to represent their economic behavior by the Smooth Transition Autoregressive (STAR) model. As noted earlier in the literature we found an existent gap in the study of rice prices in Italy, as no previous research has been conducted to study nonlinear behavior and also the presence of shift functions in the data. Let us thus explore in more detail both the data used and the corresponding modelling selection.

First, we have constructed a comprehensive database with data coming from several sources including the Ente Nazionale Risi (ENR), the Food and Agricultural Organization (FAO), and Federal Reserve System databases. We gather monthly wholesale rice price data covering the period September 1995 until August 2017 for most variables. At the moment of the research we collected all data available to ensure the most balanced and complete dataset possible. Data prior to September 1995 was incomplete for many rice varieties presenting too many challenges to conduct a thorough time-series analysis. A few peculiarities of the data are worth explaining in further detail.

First, original price data from the ENR is reported in local currency and represents the price at the Vercelli Trading Market at the time trading occurs. In this sense, our dataset comprises three distinctive periods. First from September 1995 until December 1998 prices are in nominal Italian Lire. Second from January 1999 until December 2001, in Euro under a parity convertibility of 1936.27 Lire/Euro, and lastly from January 2002 on in Euro. In addition, it is relevant to keep in mind that rice trading seasons in Italy begin at different months (normally August–September) depending on the weather (water and heat) as it relates to the first harvest. The trading season ends between April and May, and no commercialization occurs in the remaining months; that is there is no inventory carry-over; all that is harvested is sold.

Second, reported prices are the monthly wholesale weighted average for paddy. Third, the price is converted into a common currency in a three-step process, from Euro (January 1999 to August 2017), then Dollars and finally in Real Dollars (September 1995 to August 2017) [2]. Thus, all prices are per ton and in real US$, to facilitate an accurate comparison across series. More importantly, data for the wholesale price series for several varieties of rice in Italy [3] are collected; plus the price for Thai 5% is used as international price of reference for the Indica type. Given the variety of time-series length, the different trading periods, and different gaps in the data for several varieties particular attention is given to the price series that are the most complete and yield a balanced dataset. A balanced dataset is necessary when conducting time-series analysis as the one we proposed below.

Third, for the no-commercialization period between April and August we assume that prices remain stagnant with the latest price carrying over until the next commercialization season begins. This is so given that producers do not carry over inventory to the next harvest season; in other words all rice is commercialized every season.

With the intention to provide a preliminary visual inspection of the data we present Figure 1. Figure 1 includes a selected set of prices for which most of the data was complete for the period September 1995–August 2017. These series include prices for the rice varieties of: Arborio, Augusto, Baldo, Balilla, Carnaroli, Loto, Roma, S. Andrea, Selenio, Thaibonnet and Thailand 5%. It is relevant to note that not all rice varieties have complete series for the period selected for study; consequently, the subsequent analysis will be limited to a reduced number of varieties. In this selection process we use simplicity as the rule of thumb; that is, preferable to have more complete series for a longer period than having more series for shorter period.

Now that we have given a basic overview of the data and its initial transformations, we can proceed with a more formal analysis.

As noted earlier, we proceed to conduct all standard testing commonly used for time-series analysis. Following convention, time series analysis begins with the determination of the optimal lag length for each series. The optimal lag has been chosen using the Akaike Information Criterion (AIC) and Schwarz Criterion (SC) [4]. Table 1 reports these results.

Then a stationarity test of all series is carried out using the Augmented Dickey-Fuller (ADF). It is understood in the literature that in the presence of nonlinearity or structural breaks in data series usual unit root tests such as ADF may not be appropriate. Because of the importance to understand the true nature of the data it is relevant to test for the presence of structural breaks. Thus, the most advanced research in this field points out to follow the specification of the shift functions as outlined in Lutkepohl (2004) and implement unit root tests accounting for the presence of structural breaks. Some of the usefulness and uniqueness of the Shift Functions is that they have the potential to identify misspecification in unit root test identification, and thus provide a deeper understanding of nonlinearity behavior. In other words, accounting for structural breaks while using shift functions proves superior to the common ADF testing.

As noted in the literature review section we brought forth the hypothesis that the nonlinearity in rice prices might be associated with variations in a set of elements, among which we hypothesize that international rice prices (Thai 5%), as well as from the Arborio rice variety in Italy. To avoid repetition, we refer the interested reader for further elaboration on these concepts to Pede *et al.* (2018) whom provide an excellent review of the model specification for the unit root testing as well as the three alternative shift function specifications [5] following Lutkepohl (2004). Be sufficient to state that there are typically three shift functions, namely dummy, exponential and rational. For the dummy the regimes are separated by a specific point in time; the exponential allows a nonlinear gradual shift between regimes, and finally the rational contains a scalar parameter with weights between 0 and 1 to account for the transition between regimes.

Once we have completed testing for stationarity (Results presented in Table 3 and discussed later), the investigation of nonlinearity in the individual series proceeds. Recall that our sustained hypotheses are that rice prices demonstrate a non-stationary process, but more importantly that this non-stationary process is nonlinear. Consequently, the next step in the process consists of testing between a linear Auto Regressive specification against a Smooth Transition Autoregressive (STAR)-type non-linearity (Results in Table 4) [6].

Because of its importance, let us state the model specification in further detail. Following, Terasvirta (2004) a STAR model of order p can be written as:

$$x_t = \varphi_1' z_t + \varphi_2' z_t G(s_t, \gamma, c) + \varepsilon_t, \tag{1}$$

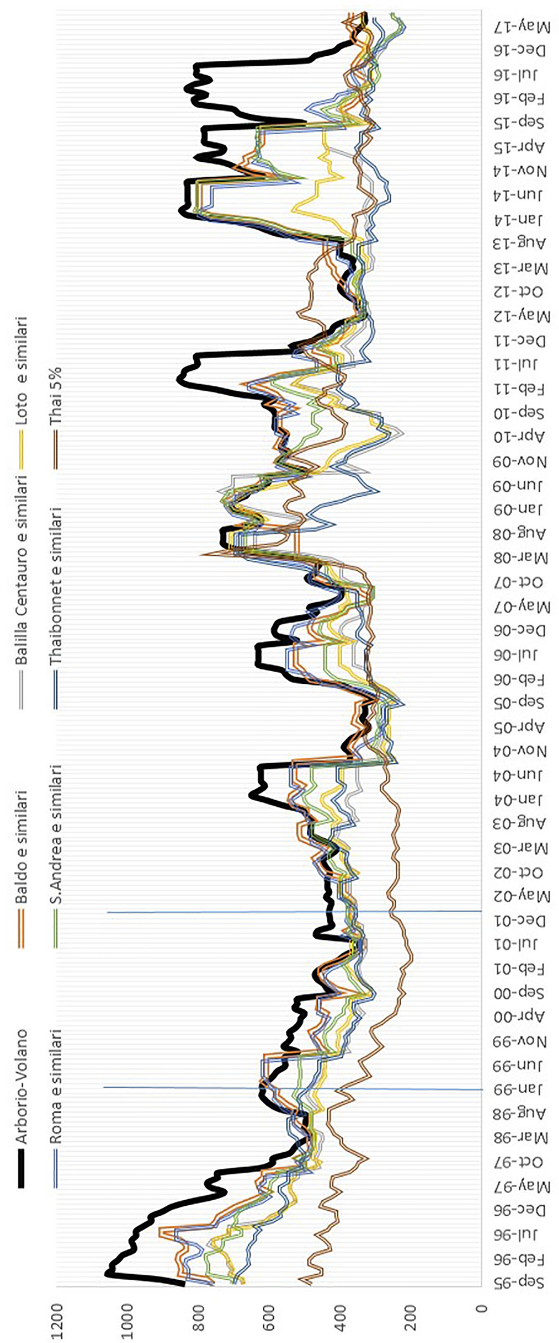

Figure 1.
Real Wholesale
rice price

where, x_t is a dependent variable; $z_t = (1, x_{t-1}, \ldots, x_{t-p}, E_t)'$ is a matrix composed of lagged dependent variables and a vector of exogenous variables E_t. The terms φ_1' and φ_2' represent parameter vectors to be estimated. In this equation, $G(s_t, \gamma, c)$ represents the transition function where s_t is a transition variable, γ represents a slope parameter, and $c = (c_1, \ldots, c_l)$ is a vector of location parameters.

As outlined by Terasvirta (2004) a transition logistic function is considered as follows:

$$G(s_t, \gamma, c) = \frac{1}{1 + \exp\left\{-\gamma \prod_{l=1}^{L} (s_t - c_l)\right\}}, \quad \gamma > 0, \tag{2}$$

where all parameters are defined as previously. It is relevant to point of that the selection of Teräsvirta STAR functional form is based on its superior properties when testing for the presence of nonlinearity over previously developed methods.

To this extent, there are two possible forms of the transition function as defined in Lutkepohl (2004). First, the logistic function obtained from Eqn (2) when $L = 1$, defining a smooth transition between two regimes at a unique location c_1. The LSTR 1 form of STAR model can be used to characterize asymmetric behavior. That is a dynamic process exhibiting periods of expansion (peak) and/or recession (trough). The second, functional (LSTR 2) form, is obtained when $L = 2$. In the latter case the dynamic processes are characterized by similar behavior at large and small values of the transition variable s_t (see Lutkepohl (2004) for more details).

Because of the relevant differences that can be drawn from the different types of nonlinearity models, a couple of considerations regarding the STAR-type dynamic processes LSTR 1 and LSTR 2 are in place here. First, a LSTR 1 model approaches the switching regression model with two regimes, each with equal variances. Secondly, a LSTR 2 model results in another switching regression model with three regimes. In LSTR2 outer regimes are identical and the mid-regime is different from the other two (Terasvirta, 2004 p. 224). Pede *et al.* (2018) note that a LSTR1 type of nonlinearity characterizes an asymmetric price dynamic with regimes of low and high values separated by a smooth transition band; known as a *logistic* smooth transition. In our analysis this could be represented by dynamic price properties being different in high production/yield years (within year/harvest season stock management and retard commercialization) versus weak/low yield years (similar to severe drought type of conditions, and higher early sells with little stock management capabilities for the rest of the year). The source of variations is year-specific, and thus unique to the planting/harvesting/commercialization within a year's period. Thus, if any, stock management practices are limited to within harvest season dynamics. This poses a real challenge for policy designs to manage price variations, as these variations are specific to each year's production and commercialization and not necessary useful across harvesting seasons.

Second, a LSTR2, known as an *exponential* smooth transition regression, is characterized by the presence of two breaking points. Here the change in the s_t transition function is

Table 1.
Lag length for prices

	AIC	SC
Arborio	4	1
Balilla	2	
Baldo	1	1
Loto	2	2
Roma	2	1
S. Andrea	2	1
Thaibonette	2	2

symmetrical for high and low values of the series; this is the typical behavior one observes in commodities that have mean reversion. The interpretation rule for the nonlinearity hypothesis indicates that rice prices response to a shock would be nonlinear and represented from a single transition from the linear estimation to the nonlinear estimation in the LSTR1 case, and consequently a dual transition difference in the case of LSTR 2.

As expected, there could be several candidates to become the transitional variable s_t. It could be for instance an exogenous variable such as changes in international rice prices (we use Thai 5% export price as the benchmark) or variation in the price level of a main domestic variety of rice, such as Arborio, per our stated hypotheses. We justify the selection of Arborio as a transitional endogenous variable because of the commercialization properties around Arborio. Recall that Arborio is considered of a higher quality and at the same time, it is the most commercialized variety of rice in Italy. Consequently, testing on non-linearity will be conducted using both variables as transition variables.

Here the transmission effects are modelled as $s_t = x_{t-d}$ and $s_t = \Delta x_{t-d}$ where $d > 0$ represents the delay parameter. The special case is when $s_t = t$ represents the Time-varying Smooth Transition Autoregressive or TV-STAR (see Holt and Craig, 2006; Teräsvirta and Anderson, 1992; van Dijk *et al.*, 2002). Each corresponding form of linearity versus non-linearity are tested, considering 5 possible transition variables:

(1) Lagged endogenous variable,

(2) Thai 5% current price,

(3) Thai 5% lagged price,

(4) Arborio current price,

(5) Arborio lagged price [7]

4. Results and discussion

4.1 Unit root and stationarity tests

We begin this section by exploring the results of optimal lags determination as reported in Table 1. Looking at the estimated results and following the Schwartz Criterion, the mode value for wholesale price was one-month lag.

Next, we present the test for stationarity and present first the ADF test results, under the assumption of linearity in the price series in Table 2. Correspondingly, Table 3 shows results of unit root tests with structural breaks. Notice the apparent similarity of results among tests; yet not identical between the alternative model specifications. Particularly several tests in Table 2 indicate rice price series are I (1) in levels, or hold only marginal significance for the rest. However, and more importantly, this result does not hold when accounting for structural breaks. This evidence is in line with the material presented in the literature review where previous studies have found nonlinearity in the prices of several commodities as well; see Roll (1984); Boudoukh *et al.* (2007); Pede *et al.* (2018); Ubilava (2012); Reitz and Westerhoff (2006); Mainardi (2001); Holt and Craig (2006); Holt and Balagtas (2009); and Ubilava and Holt (2013) for instance. In the latter case, there is a good number of price series that when measured in level are I (0), that is they are non-stationary and possess a unit root. Therefore, in the presence of structural breaks, testing for stationarity is strictly preferred with the use of shift functions and not with the typical ADF. This first result is relevant as it confirms the assumption about the data yielding strong and robust evidence in favor of the structural break hypothesis. Furthermore, the evidence points out to the presence of price dynamics that could easily be confused with state dependent or regime switch events. Notice that the testing of structural breaks in JMulti provides a suggested date for the break to take place, as reported in Table 3. This suggestion serves as evidence of clear and distinctive structural

	Period	ADF test statistic Level	First lag
Arborio	Sep 95–Aug 2017	−2.467 (0.125)	−14.869 (0.001)***
Augusto	Oct 2010–Aug 2017	−2.408 (0.143)	−9.164 (0.001)***
Balilla	Sep 95–Aug 2017	−2.742 (0.068)*	−14.656 (0.001)***
Baldo	Sep 95–Aug 2017	−2.627 (0.089)*	−15.55 (0.001)***
Carnaroli	Nov 2007–Aug 2017	−3.03 (0.035)**	−9.033 (0.001)***
Loto	Sep 95–Aug 2017	−3.055 (0.031)**	−11.894 (0.001)***
Roma	Oct 95–Aug 2017	−2.289 (0.176)	−14.534 (0.001)***
S. Andrea	Sep 95–Aug 2017	−2.34 (0.160)	−14.581 (0.001)***
Thaibonette	Oct 95–Aug 2017	−3.155 (0.024)**	−13.598 (0.001)***

Note(s): *, **, *** Statistically significant at 10%, 5%, 1% respectively
All Prices in Real US $ 2010 = 100

Table 2.
Unit root test with ADF

	Structural break	Shift dummy		Exponential shift		Rational shift	
	Used (date)	Level	First difference	Level	First difference	Level	First difference
Arborio	(2016 - M 10)	−3.427**	−3.075**	−3.393**	NA	−3.301**	−6.818***
Balilla	(2009 - M 9)	−1.675	−1.498	−1.572	−1.505	−1.892	−1.734
Baldo	(2015 - M 9)	−3.146**	−3.050**	NA	−3.079**	−3.285**	−5.231***
Lotto	(2004 - M 9)	−2.788*	−3.100**	−2.731*	−3.135**	−3.153**	−7.558***
Roma	(2015 - M 9)	−3.333**	−3.922***	NA	−3.613***	−3.455**	−3.732***
S. Andres	(2014 - M 10)	−2.588*	−2.50*	−2.547	−2.465	−3.239**	−4.623***
Thaibonette	(2008 - M 10)	−2.375	−2.169	−2.042	−2.199	−2.298	−6.225***
International Rice							
Thai 5%	(2008 - M 4)	−2.236	−0.933	−0.933	−0.985	−2.729*	−1.2867

Note(s): *, **, *** Statistically significant at 10%, 5%, 1% respectively
All Prices in Real US $ 2010 = 100

Table 3.
Unit root test with structural breaks

breaks in the series, best modeled as smooth transitions instead of linear models. This is relevant when analyzing price time-series as it is important to differentiate them from state dependent or regime switching events.

There is also the hypothesis that perhaps the presence of random exogenous and systematic endogenous shocks has resulted in the divergences observed and consequent non-stationarity in rice price when expressed in levels. The results also prove that stationarity is achieved once the tests are conducted using first difference in the data.

At this juncture the first significant contribution of the study is supported by the results from the shift function estimations which provide robust evidence of a non-linearity behavior in prices. At this point all estimated models are statistically significant at the 5% level or better. It is evident that the introduction of the shift functions allows for a transition process that is smoother; allowing incorporating what otherwise might be classified as regime switch events. Most notably the presence of a shock (shift) results in stationarity.

4.2 Nonlinearity and STAR model

Following the results supporting the presence of unit-root and the need to account for shift functions to achieve stationarity in the series and consequent recommendations from the previous section we proceed to test the null hypothesis 1 of linear model versus non-linear TV-STAR models using rice prices in first differences. In cases where a non-linear STAR model is detected, the procedure also allows estimation of the model with the appropriate functional form for the transition function; that is either LSTR1 or LSTR2, as it was discussed in the modelling section and in addition to the evidence found in the literature review.

To illustrate the results of the nonlinearity tests, Table 4 reports the results for all prices. Tests were carried out with respect to an endogenous lagged own price variable; as well as the Thai 5% broken rice price. In addition, the paper brings forth the hypothesis that rice prices in Italy may be highly determined by the trading patterns of the most commercialized type, Arborio. That is, we proceed to test Hypotheses 2 and 3 respectively.

4.3 Lagged own price

The lagged-own price results for linearity versus nonlinearity yield some interesting and mixed outcomes. First, we observe LSTR1 asymmetric price behavior for Arborio and Thaibonnet; whereas all other varieties follow a linear specification to their own-lagged price. This indicates the presence of very diverse price formation that are variety specific. When looking at Arborio, variations on own-lagged price drive current price in an asymmetric fashion, with distinctive oscillations that are different when prices increase than when they decrease. We argue the same for Thaibonnet (only Indica type of rice in Italy). To illustrate this point, Figure 2 shows that in the case of Arborio upward variations in price tend to be more abrupt than downward shifts. This behavior is in line with the typical characteristics of a LSTR1 transition functional form. For Thaibonnet, its price behavior follows very closely the price of Thai 5%. In addition, a two-regime behavior is observed, where prior to 2004 the price of Thaibonnet was consistently higher than Thai 5%, and after March 2008 Thaibonnet has a lower price than Thai 5%. During 2004 and 2008 the relationship yields mixed behavior. Thus, the evidence confirms Hypothesis 1 in some cases and rejects it in others.

4.4 Transition variables

Testing indicates a rejection of the null hypothesis (linearity) for most prices when referring to Thai 5% and Arborio as transition variable, confirming Hypotheses 2 and 3. These are

		With Thai 5% and Arborio as transition variables			
	Lagged	Thai 5%		Arborio	
	Price	Level	Lagged	Current	Lagged
Arborio	LSTR 1	Linear	Linear	n/a	n/a
Balilla	Linear	Linear	LSTR 1	LSTR 2	LSTR 1
Baldo	Linear	LSTR 2	LSTR 2	LSTR 2	Linear
Loto	Linear	LSTR 1	LSTR 2	LSTR 2	Linear
Roma	Linear	Linear	LSTR 2	LSTR 2	LSTR 1
S. Andrea	Linear	LSTR 1	LSTR 2	LSTR 1	Linear
Thaibonette	LSTR 1	LSTR 2	LSTR 2	LSTR 2	Linear

Table 4.
Nonlinearity tests. Data in first difference

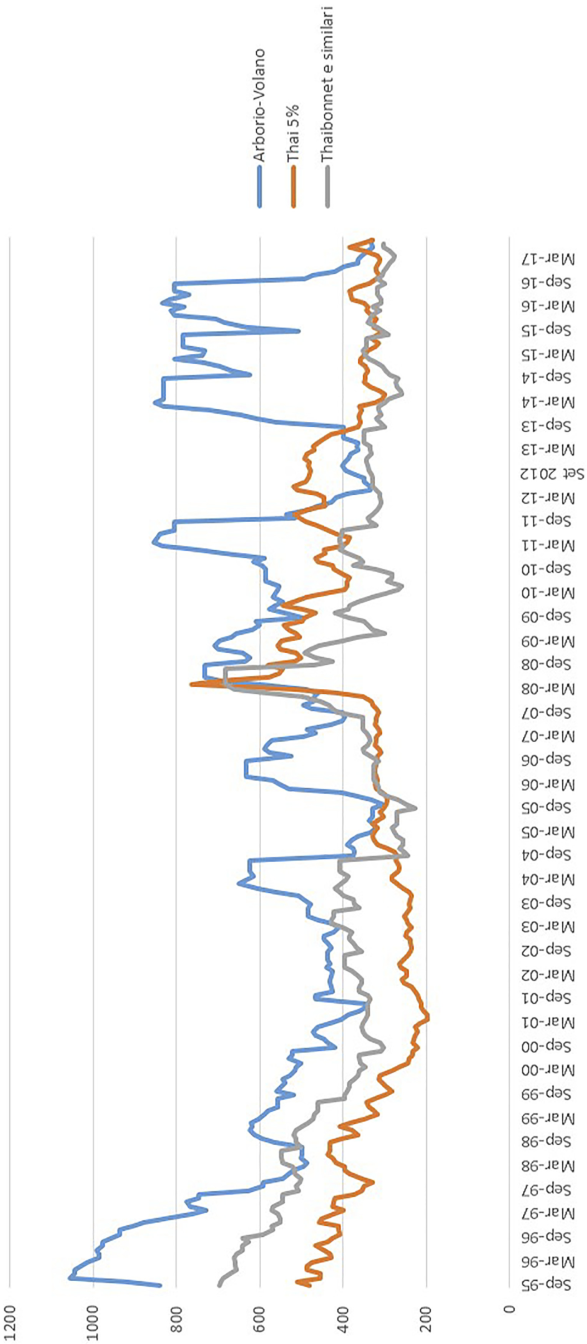

Figure 2.
Selected rice variations, real price in US dollars

important results and as noted possibly the first of their kind for the case of rice pricing in Italy. Interesting enough, for the case of Arborio, Thai 5% presents a linear relationship both current and lagged. Upon rejection of the linearity null hypothesis when applicable, then it was needed to decide which type of nonlinear model to use between LSTR 1 and LSTR 2.

As it was stated earlier in the paper, it is common wisdom in agricultural markets to observe both commodity prices variations throughout the year and across years. However, such observed variations should not be classified as surprise or regime switch type of events most of times. Following Boudoukh *et al.* (2007) we argue that rice price dynamics formation in Italy are highly related to endogenous factors associated to the harvest season itself. For instance, while irrigation is widely available in almost all paddy, temperature and humidity are exogenous to production affecting the initial time of harvest and its duration, as well as yield from year-to-year. However, the results of variations on temperature and possible diseases may have implications both on quality and yield variation. In this context, producers and wholesale buyers derive a large amount of information from the first harvest recollection of the crop within the season, normally serving as a lead indicator of the overall season harvest dynamics, and consequently price formation. Also, planting decisions could be affected by the performance of the previous year's harvest as well as the last previous season trading price(s). The interesting dynamics here revolve around the difficulty to forecast price formation, since the statistical evidence clearly indicates the presence of non-stationarity and nonlinear behavior. Furthermore, the properties of the time-series are undoubtedly indicating that the price formation behaves in different ways when prices are high than when prices are low.

There are several reasons that come to mind when exploring the observed nonlinearity behavior in prices. First, it is possible that the intrinsic characteristics of the Indica and Japonica are different enough so that the two price series are not directly correlated in a linear fashion. Second, the correlation coefficient between Arborio and Thai 5% is only 33%, and the Granger causality test indicates that neither Granger causes the other (see Table 5).

In addition, it is also relevant to note that the possibility for consumption substitution effects from one variety (Japonica ↔ Indica) to the other is not present at the price ranges observed in the series. However, the already present shift in land allocation, and the increase to about 60,000 hectares of Indica rice production in Italy, as of 2018, are a direct reflection of changes in the fundamentals of the market dynamics. The land substitution effect consequently manifests itself – at least partially and nonlinearly – in the variation depicted in the price series for Japonica varieties per our discussion. These effects could be exacerbated further as a consequence of the COVID-19 pandemic related events. Of course, it is too early to tell as most decisions for the current harvest season have been finalized. This is an interesting research topic beyond the scope of this study at this time.

However, what emerges is a consistent increase in land allocation to the production of Indica type of rice to meet the growing demand. Furthermore, under this rationality, we could expect that variations on the exogenous transmission effect (Thai 5%) would only produce nonlinearity effects in the presence of one state of nature. This state of nature would be a clear regime switch type of event where significant and new information may be derived from oscillations relating to significant variation in the Thai 5% market conditions. Anything else would appear to be driven by market fundamentals. Put simply, when linearity is detected, variations in the price of Thai 5% have oscillated within the expected normality of the

Null hypothesis	Obs	*F*-statistic	Prob
Thai5 does not Granger Cause ARB	262	1.60169	0.2036
ARB does not Granger Cause Thai5		0.59530	0.5522

Table 5.
Granger causality test

market, in relation to the development of possible substitution effects from Japonica to Indica. However, it is relevant to point out that Thai 5% has a linear effect on Arborio, but not in relation to the other Japonica varieties. Thus, the paper proposes to break the analysis down between Arborio and then the rest of the Japonica varieties; plus Thaibonnet. The reason is that Arborio is used as a transition variable for all other rice varieties [8]. Looking at Arborio first, it is possible to observe the presence of a LSTR1 own lagged price dynamic behavior, indicating that upward and downward variations in lagged price result in differentiated price variations. More specifically the market reacts differently to news on previous price being high than low. In addition, the use of Thai 5% as transition variable results in a linear model specification, indicating that Thai 5% price oscillations result in symmetric effects on the price of Arborio.

Table 4 presents the analysis for the rest of the prices. Here the evidence overwhelming supports the presence of nonlinearity dynamics of price formation. First, there is a dominant presence of LSTR2 (exponential smooth transition) dual behavior as a result of variations in the Thai 5% (lagged) and Arborio (current). Arborio as a transition variable (current) creates a symmetric effect in the variation of prices of almost all other rice varieties, which indicates that rice prices would move in the same fashion to upswing in Arborio price as they do to downturns; but differently around their mean. This evidence is congruent with the hypothesis that most prices tend to follow the Arborio lead when increasing and decreasing, but act more independently when prices gravitate around the mean. Now the Arborio lagged transition variable has predominantly a linear effect, indicating that most of the expected variation is absorbed relatively quickly.

When looking at the effects of Thai 5%, there is a consistent presence of LSTR2 effects from the Lagged price on almost all varieties of rice, but only linear on Arborio. In this context the nonlinearity specification is particular interesting for the Baldo and Thaibonnet varieties. Because of its inherent differences, a particular attention to the Thaibonnet variety must be paid since it is part of the Indica family of rice. Notice how the Thaibonnet demonstrates a LSTR1 behavior to its own lagged price, and then consistent LSTR2 to Thai 5% (level and Lagged) as well as LSTR2 to Arborio current.

In general, the presence of LSTR2 deriving from Thai 5% and Arborio, reflect different states of nature. Notice that while both prices generate LSTR2 type of nonlinearity on all rice varieties included in the analysis, Thai 5% does so through the lagged price, while Arborio does it through the current price. In addition, notice that Thai 5% also has a LSTR2 effect on Thaibonnet type of rice at the current price level. Our reading/interpretation of the observed price behavior indicates that within the same type of rice (Japonica), Arborio price variations lead to a concurrent price adjustment in the same period, whereas variations occurring in the international prices have a lagged effect on the price formation process. In addition, clear and robust evidence indicates that the transmission effects are nonlinear, as typically assumed and in favor of Hypothesis 2 and 3. However, effects deriving from Arborio become linear after the initial concurrent shock has been incorporated; this is reflected in the linearity effect observed in the lagged Arborio price effect, for most all varieties. This becomes as well a topic of further research. We hypothesize that price response due to COVIV-19 related transformations in the market fundamentals will most likely result in higher volatility in price formation processes.

From the reverse perspective, international price effect transmission approximated by the lagged Thai 5% pricing following a LSTR2 transmission effect on almost all varieties; with Balilla following a LSTR1, and linear on Arborio. Furthermore, Thai 5% presents either a linear effect or LSTR1 when using current price level as the transmission effect; with the exception of Thaibonnet and Baldo showing a LSTR2 pattern of adjustment. For the rest of the variations, LSTR 1, this implies that the dynamic properties are asymmetric with a larger effect on one of the ends of the price variation. Visual observation of the real price diagram makes us hypothesize that the variations are much more abrupt and significantly pronounced as prices increase. Once again, the effects of COVID-19 changes become a relevant topic of research in the process of price formation for rice, as well as any other food commodity.

5. Implications and conclusions

The analysis herein developed allows us to state that predicting price variability and their transition dynamics to long-run equilibrium is therefore a fundamental topic of interest for researchers, with significant implications for policy makers. The results of the alternative model estimations, demonstrate that rice prices in Italy are driven by nonlinearity. This is a robust and precise result.

With about 4,000 producers, all almost of small size and highly concentrated in three provinces in the Po Plain in the Northern Region of Italy, the rice sector still remains unorganized and not cohesive. Rice commercialization and its pricing are still the result of the decisions of individual producers. This situation may result in higher levels of exposure to the presence of negative events which may accelerate price change and variability. As noted, the current global pandemic related to COVID-19 may have large and unexpected magnifications of the nonlinearity nature of prices found in this study. With these considerations in mind, the application of STAR nonlinearity testing to rice price time-series in Italy yields several unique and robust results. Using lagged-own prices we found that prices have linear effects on all rice varieties, with the exception of Arborio and Thaibonnet, which yield a LSTR1 type of nonlinearity to their respective lagged price. Both varieties react in an asymmetric fashion to price variations with different reactions to increases in price than decreases. Since these two varieties are dominant in the market the implications could be large. Furthermore, recent developments in the Italian rice market and the significant increase in imports of the Indica type, as well as the increase in land allocation to the production of Indica in Italy, point out to a higher degree of responsiveness of Thaibonnet type than Arborio to these possible variations.

Second, the empirical evidence indicates that the relationship between Arborio and Thai 5%, is linear in nature (when the lagged and level Thai 5% is used as transition variable); whereas Thaibonnet reacts in a LSTR 2 fashion to both changes. Perhaps more importantly, when using the price of Arborio as the transition variable, our results indicate that transition effects work their way into all other rice varieties in a clear nonlinear fashion. In addition, Thaibonnet reacts in a LSTR 2 when Arborio current price is used as the transition variable. This evidence seems to indicate that Thaibonnet reacts counter cyclically to variations in both Arborio and Thai 5% prices oscillations. Thaibonnet price increases as a response of price decreases in Arborio and increments in the Thai 5%. In contrast, Thaibonnet decreases in price as Arborio increases and Thai 5% decreases.

The nonlinearity determined in this study has at least two main components. First, there is the effect deriving from variations of Arborio prices. These variations are for the most part of the LSTR2 type; symmetric on the ends and different around the mean. Secondly, variations in the international price of rice (approximated by Thai 5%) generate a mix of effects on Italian rice prices, both LSTR 1 and LSTR 2. On the one hand, the presence of LSTR 1 might be explained as the initial shock on the market, and the LSTR 2 as the second wave of effects. However, when looking at the Thaibonnet variety (Indica produced in Italy), variations on the international price are of the LSTR 2 type; that is symmetric on the tails and with a mean reversion effect. Concerning Arborio, there is a linearity process in relation to variations in the international price, and LSTR 1 (asymmetric behavior) to its own lagged price. Thus, the evidence of non-linear STAR-type dynamics, indicates that wholesale rice prices are significantly affected by variations in the international price of rice, as well as variations in

Arborio price. In sum, the rice prices in Italy seem to be affected more often by regime switch events than state-dependent situations. In light of the evidence, understanding rice pricing dynamics and possible nonlinearity behavior is pivotal for the future and the survival of the entire European and Italian rice supply chain. Thus, policy recommendations for the production and commercialization of rice in Italy, should be based on nonlinear models, to better portrait the price behavior and reduce the possibilities to generate biased effects if linear models were to be used. Government interventions at the national agricultural policy level should take into account also the European regulatory framework in which the Italian rice system operates.

6. Limits and future research

If, on the one hand, the article provides an interesting scientific and empirical contribution on nonlinearity rice price dynamics, the research presents some limitations. As in any study, there are several limitations that we would like to state. First, we conduct our work using on single commodity, rice. In addition, this is a single country study, exclusively focusing on the Italian market. Hence, it would be very interesting to extend the work perform in here to other crops and countries.

Future research might be carried out to better understand the sources and nature of the oscillation on prices within a year and across years. It would be of interest to understand how producers may conduct within-year stock management in relation to the behavior of markets fundamentals as reflected by prices both of domestic and international rice varieties. This, of course, is in line with the theory of nonlinearity which states, that in the presence of nonlinearity forecasting becomes a troublesome and daunting task. It would further be of interest to model the price responses to possible changes to the current zero-tariff import policy in place in the EU.

In addition, the current state of the world economy and the effects deriving from the COVID-19 pandemic are of course relevant topics to include in future research. On this line, modelling increase variability related to nonlinearity behavior in rice prices (and any other food commodity) is of the outmost importance as we moved forward in understanding price oscillations in what we expect an upward trend. All these topics are nevertheless beyond the scope of this paper.

Notes

1. Around the world, rice production is distributed as follows. Africa accounts for 4% of total paddy production, with Egypt, Nigeria and Madagascar as main producers. Latin America and the Caribbean produce close to 3% of total production, with Brazil absorbing nearly half of the total paddy production in this region, followed by Peru, Columbia and Ecuador. The United States contributes 2% of 2017 global rice production; mainly from California and the Southern states along the Mississippi River.
2. USD to EURO exchange rate for each month. In addition, since the Euro was first introduced in January 1, 1999, at a conversion fixed rate of 1,936.27, rice prices were converted between this date and the official introduction of the Euro into US$ first, and then proceed to the conversion in terms of Euros.
3. The different varieties of rice included in the database are Arborio-Volano, Ariete, Augusto, Baldo e similari, Balilla Centauro, Carnaroli, Gladio, Cripto-Elio, Indica Vari, Drago, Flipper Lido, Roma, S. Andrea, Selenio, Thaibonnet and Sole. As noted, different varieties are commercialized during different periods.
4. In case where there are differences in the orders suggested by the AIC and SC, it is considered the lag order suggested by the SC, as suggested in Lutkepohl (2004).

5. Owing to Lutkepohl (2004) three alternative shift function specifications to test for the presence of structural breaks are used. These are the shift dummy function, the exponential shift function and the rational shift function.
6. See Terasvirta (2004) Chapter 6 in Lutkepohl (2004) for a complete and detail discussion.
7. Estimations in this study are performed with JMulti. It is an interactive software for time series analysis. Readers can visit http://www.jmulti.de/ for more details.
8. The other Japonica variety that has the most similar properties as Arborio, and could be easily substituted for is Carnaroli. However, Carnaroli was initially traded as part of the Lunghi A group and began individual trading until 2007. Thus, given the need for a balance sample, it is not included in this analysis.

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