Informational inefficiency in the principal olive oil markets of the EU

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Abstract

This work investigates informational inefficiency in the olive oil markets of Spain, Italy, and Greece using weekly national prices from 2017 to 2022 and a flexible approach that allows for different types of serial dependence patterns (i.e. long-memory, local correlation, and entropy). The empirical results suggest: (a) All six markets considered have exhibited statistically significant informational inefficiency; (b) The lack of sufficient complexity has been, in the majority of cases, more important for the informational inefficiency relative to long-memory and to local correlation; (c) There have been both similarities and differences in the dynamics of prices across the markets. The former may be explained by the substitution possibilities while the latter may be attributed to the special characteristics of each individual market.
Keywords: Informational inefficiency; autocorrelation; olive oil; EU
JEL Classification: Q11, C1

1. Introduction

In Economics, the term informational efficiency refers to how fast and accurately markets reflect the available information. Informational efficiency itself is a necessary condition for the optimal allocation of scarce resources and, in turn, for the maximization of economic welfare. Fama (1965) advanced the efficient market hypothesis (EMH) that, in its weak version, posits that traders are completely rational and prices reflect all available past information[1]. From a statistical viewpoint, (logarithmic) price levels in informationally efficient markets are random walk processes and price changes (log-returns) are white noise processes. Samuelson (1965) put forward a less restrictive statistical characterization under which prices in informationally efficient markets are martingales. Although certain technical differences exist between the two characterizations, both imply that price log-returns are not serially dependent; that means, past prices cannot predict future prices. Informationally efficient markets, therefore, posses a fair-game pattern and no trader expects to attain systematically abnormal profit (Cox *et al*., 1982; Buccola, 1984; Kristoufek, 2018). The assumption of complete rationality has been challenged by Sefrin (2000) and Shiller (2003), who argued that sentiments (fear and greed) influence the behavior of market participants and Lo (2004) who allowed for limited trader rationality. For them, mass psychology, accumulation of knowledge from past mistakes, and reliance on trial and error processes may compromise informational

[1] Depending on the type of information available, the EMH may assume one of the following three forms: weak (information about past prices), semi-strong (public information), and strong (all information, including private one) (Brorsen *et al*., 1984; Kristoufek and Vosvrda, 2016).

efficiency and, as a result, price returns may be predictable not only in the short- but in the long-run as well.
The investigations on the strength and the pattern of serial dependence for agricultural commodities prices have been carried out through a variety of statistical tools. Early empirical works (Cox *et al*., 1982 and Brorsen *et al*., 1984) employed standard linear AR models on price returns. Gradually, however, it became clear that the autocorrelation structures are very likely to be non-linear (that is, varying with the time scale and/or with the size of shocks considered). More recent studies, therefore, have relied on less restrictive approaches such as the Fractional Integration (Jin and Frechette, 2004), the Rescaled-Range Analysis (Turvey, 2007), and the Multifractal Detrended Correlation Analysis (Li and Lu, 2011; Yin and Wang, 2021).
The verification (through tests of serial dependence) of whether an agricultural commodity market is informationally efficient or not is certainly an interesting research exercise. Even more important, however, are the answers to the following questions: (a) if returns are correlated, how far the market is from the ideal state (i.e. from full informational efficiency)? (b) if there multiple types of autocorrelation (as is typically the case for non-linear dependence structures), what the contribution of each type of autocorrelation to the overall level of inefficiency is?
Against this background, the objective of the present work is to investigate informational inefficiency (in its weak form) of the olive oil markets in Spain, Italy, and Greece. The EU is the leading producer, consumer, and exporter of olive oil in the world. It accounts for 67 percent of global production, 53 percent of global consumption, and it exports around 0.57 million tons every year. About 95 percent of the olive oil supply in the EU comes from three members, namely, Spain (66 percent), Italy (15 percent), and Greece (13 percent) (European Commission, 2021; Mili and Bouhaddane, 2021). From an economic standpoint, the most important qualities of olive oil produced in the EU are the extra-virgin and the virgin ones.
The main contributions of this work to the literature on informational efficiency are:

(a) It appears that it is the first empirical study focusing on agricultural commodities markets in the EU; to the best of my knowledge, all earlier ones have considered US and (to a lesser extent) Chinese markets.

(b) It relies on a flexible approach, proposed by Kristoufek and Vosvrda (2014a and 2014b), that is capable of accommodating different types of serial dependence and assessing the contribution of each type to informational inefficiency.

In what follows, section 2 presents the analytical framework and section 3 the data, the empirical models and the results. Section 4, offers conclusions and suggestions for future research.

2. Analytical framework

Let Θ_i $(i = 1, 2, \ldots, n)$ be a bounded measure of informational efficiency.

Kristoufek and Vosvrda (2014a and 2014b), proposed a composite index of informational inefficiency that is based on the distance between the actual values of $\Theta's$ and their respective values in the ideal market state (i.e. under full informational efficiency). Specifically, the composite index (*I_INEF*) is defined as

$$(1) \quad I\_INEF = \sum_{i=1}^{n} \left(\frac{\hat{\Theta}_i - \Theta_i^*}{R_i}\right)^2 ,$$

where $\hat{\Theta}_i$ is an estimate of Θ_i, Θ_i^* is the expected value of Θ_i in the ideal market state, and R_i is the theoretical range of Θ_i.

Kistoufek and Vosvrda (2014a, 2014b, and 2016) and Kristoufek (2018), consider three bounded measures of informational efficiency; namely, the *fractal dimension* (*D*), the *Hurst exponent* (*H*), and the *approximate entropy* (*E*). The fractal dimension (Mandelbrot, 1967) captures the roughness of a stochastic process (here, a price time series) and it can be viewed as a measure of local (short-run) dependence/memory. For a weakly stationary process, *D* lies in [1, 2] (meaning that $R_D = 1$). When *D*=1.5, the process is locally uncorrelated. When *D*>1.5, the process exhibits short-run anti-persistence (meaning that a positive (negative) change in the current time interval is likely to be followed by a change of the opposite sign in the next non-overlapping time interval). Local anti-persistence is consistent with a high level of roughness and it is reflected in the presence of local bursts in price volatility. When *D*<1.5, the process shows local persistence (meaning that a positive (negative) change in the current time interval is likely to be followed by a change of the same sign in the next non-overlapping time interval). Local persistence is consistent with a low level of roughness and it is reflected in the presence of short-run trends.

The *Hurst exponent* (Hurst, 1951), captures the long-run correlation structure (global or long-range dependence/memory). For a weakly stationary process *H* lies in [0, 1] (meaning that $R_D = 1$). When *H*=0.5, the stochastic process has no long-range dependence (i.e. it changes sign as frequently as an uncorrelated one). When *H*>0.5, the stochastic process shows global persistence and when *H*<0.5 it exhibits global anti-persistence. In general, the local correlation structure is independent of the long-range one (for example, a *D* < 1.5 does not necessarily imply an *H*>0.5). *D* and *H*, therefore, may provide different insights about the dynamics of a time series and it is worth investigating them separately (Kristoufek and Vosvrda, 2013)[2].

Entropy is a measure of complexity. Processes with high entropy involve high uncertainty (randomness) while those with low entropy can be viewed as deterministic. In informationally efficient markets, prices exhibit maximum entropy (Pincus, 1991). For a weakly stationary price series, *E* lies in [0, 1] with 0 corresponding to a deterministic process and 1 to the ideal market state. To ensure that in the calculation of the composite index all individual correlation measures have exactly the same maximum distance (0.5) from their respective values in an ideal market state, Kristufek and Vosvrda (2014a and 2014b) and Kristufek (2018) suggest rescaling the approximate entropy range to $R_E = 2$. Their suggestion has been followed in this work as well.

3. The data, the empirical models, and the empirical results

The data for the empirical analysis are weekly national cash (spot) prices of extra-virgin and virgin olive oil in Spain, Italy, and Greece from the 1st week of October 2017 (that is, the beginning of the marketing year 2017/18) to the 4th week of May 2022[3].

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[2] The local dependence structure is perfectly reflected in the global one only for self-affine processes. A self-affine process is invariant in distribution under suitable scaling of time (that is, it behaves in exactly the same way when viewed at different time scales). Technically, for self-affine processes, it is the case that *H*=2-*D* (Kunsch, 1987).

[3] They have been obtained from https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/prices/price-monitoring-sector/plant-products/olive-oil_en. The beginning of the sample has been constrained by data availability (consistent information on the national price of extra-

They refer to the wholesale level and are expressed in Euros per 100 kilograms. Virgin olive oil is produced directly from olives and solely by mechanical means. The extra-virgin, has the highest quality from an organoleptic point of view; it has no defects and its acidity level does not exceed 0.8%. The virgin, has some light sensory defects and its acidity level does not exceed 2%.

As noted by Cox *et al*. (1982), the investigation of informational inefficiency from cash agricultural commodities prices poses certain difficulties which, for most parts, are not very relevant when the empirical analysis relies on futures prices. In particular, fundamental factors such as storage costs, seasonality, and long cycles may induce autocorrelation in price returns. In olive oil markets, the highest prices are typically observed at the beginning and at the end of the marketing year. Also, a bad or a good harvest in a given year may affect prices in the next year. It is necessary, therefore, to account for the influence of these factors on the dynamics of the time series prior to testing for informational efficiency and to calculating inefficiency indices. Because fundamental factors are typically unobservable, the standard practice is to approximate them by a number of observable variables (Cox *et al.*, 1982; Brorsen *et al*., 1984). Here, to remove the influence of fundamental factors each logarithmic price series has been regressed on yearly and monthly dummies; then, the residuals of each regression have been first differenced to generate "filtered" price log-returns; these, in turn, serve as proxies for pure random shocks to the underlying price series (Cox *et al.*, 1982). Table 1 shows the results from the application of the KPSS unit root tests on the "filtered" price log-returns. In all cases, the null hypothesis (weak stationarity) is not rejected.

Tab. 1. *Unit root tests on the "filtered" price log-returns*

Market	Test Statistic	Market	Test Statistic
IT_XV	0.097	IT_V	0.048
GR_XV	0.047	GR_V	0.054
SP_XV	0.043	SP_V	0.038

Notes:
(a) KPSS test with a constant; the critical values are 0.347, 0.463, and 0.739 at the 10, 5, and 1 percent level, respectively.
(b) IT_XV, GR_XV, and SP_XV denote the extra-virgin olive oil markets in Italy, Greece, and Spain, respectively; IT_V, GR_V, and SP_V denote the virgin olive oil markets in Italy, Greece, and Spain, respectively.

Individual and joint tests of significance have been conducted using a Wald-type test with statistic

$$(2) \quad W = (R\hat{C})'(R\hat{V}_C R')^{-1}(R\hat{C}),$$

where *R* is the restrictions' matrix, *C* is the parameters' vector, and $\hat{V}_C$ is the bootstrap estimate of their variance-covariance matrix (Patton, 2013). *W*, under the null hypothesis, follows the χ^2 distribution with degrees of freedom equal to the number of restrictions. All calculations have been carried out in *R*. In particular, the fractal dimension has been estimated using the package Fractaldim (Sevcikova *et al*., 2021);

virgin oil in Italy). For some weeks, price information on one or more national markets was missing. The total number of available observations for the empirical analysis is 211.

the Hurst exponent using the package nonlinearTseries (Garcia, 2021); and the approximate entropy using the package TSEntropies (Tomcala, 2018).

Tab. 2. *Tests on the departure of the individual serial dependence measures and of the composite inefficiency index from their respective expected values in an informationally efficient market*

	Market					
Measure	IT_XV	IT_V	GR_XV	GR_V	SP_XV	SP_V
Long-Range Dependence	-0.076 (0.484)	-0.1 (0.389)	-0.235 (0.048)	-0.303 (<0.01)	-0.039 (0.717)	-0.027 (0.798)
Fractal Dimension	-0.2 (0.109)	-0. 384 (<0.01)	0.085 (0.566)	0.036 (0.827)	0.085 (0.579)	0.132 (0.387)
Entropy	-0.599 (<0.01)	-0.577 (<0.01)	-0.495 (<0.01)	-0.478 (<0.01)	-0.544 (<0.01)	-0.539 (<0.01)
Composite Inefficiency Index	0.368 (<0.01)	0.491 (<0.01)	0.351 (<0.01)	0.388 (<0.01)	0.288 (<0.01)	0.302 (<0.01)

Notes:
(a) IT_XV, GR_XV, and SP_XV denote the extra-virgin olive oil markets in Italy, Greece, and Spain, respectively; IT_V, GR_V, and SP_V denote the virgin olive oil markets in Italy, Greece, and Spain, respectively.
(b) The null hypothesis for long-range dependence and for fractal dimension is that the value of the measure is equal to 0.5; for entropy, it is that the value is equal to 1 while for the composite inefficiency index that it is equal to 0. The statistics are departures of the sample estimates from their respective expected values at an ideal state.
(c) *p*-values in parentheses, obtained using block-bootstrap (Politis and Romano, 1994) with 2500 replications.

Table 2 presents tests on the departure of the correlation measures and of the composite inefficiency index from their respective expected values under full informational efficiency. All statistics that are related to long-range dependence are negative; however, only those for the extra-virgin and the virgin olive oil markets in Greece are statistically significant at the 5 percent level or less. One may conclude, therefore, that prices in the olive oil markets of Greece have exhibited global anti-persistence while those of Italy and Spain have shown no long-range memory. From the statistics that are related to fractal dimension, two (both for the Italian market) are negative and the remaining four are positive; however, only that for the virgin olive oil market in Italy is statistically significant at the 5 percent level or less (pointing to presence of local persistence); for the remaining five markets the null hypothesis (absence of short-run memory) appears to be consistent with the data. A comparison of the long-range dependence and the fractal dimension measures by market, suggests that the price series are likely to be self-affine for IT_XV, SP_XV, and SP_V but not for IT_V, GR_XV, and GR_V. In particular, while prices in Greece have shown no local dependence they both have exhibited global anti-persistence; similarly, while the price in the IT_V market has shown short-run persistence it lacked long-run memory. All statistics that are related to Entropy are negative and strongly statistically significant. Prices in the Greek markets have achieved the highest scores for *E* (i.e. they have exhibited the highest level of complexity) while those in the Italian markets the lowest ones (i.e. they have been the closest to a deterministic process)[4]. The composite inefficiency indices are, in all cases, statistically significant at the 1 percent level or less. The two Spanish markets have achieved somehow lower inefficiency scores relative to those in Italy and Greece.

Cox *et al*. (1982) found that the cash markets for sorghum and corn in the US were informationally inefficient while that for feeder cattle was efficient. Brorsen *et al*. (1984) also reported evidence of inefficiency for both the cash and the futures markets of corn in the US. Li and Lu (2011), found that the futures markets for sorghum, hard wheat, and corn in China showed global anti-persistence whereas that for soybeans global persistence. Turvey (2007), assessed long-range dependence for the futures prices of 11 agricultural commodities in the US and reported values close to 0.5 (i.e. in the range 0.425-0.555). Kristufek and Vosvrda (2014a) investigated 15 agricultural futures markets in the US including grains, livestock, and softs. In most cases, the price returns turned out to be locally persistent but globally anti-persistent; the approximate entropy measure ranged in 0.4 to 0.97; softs turned out to be the most informationally efficient group (with a composite inefficiency index less than 0.1) whereas livestock the least efficient one (with a composite inefficiency index about 0.25).

In an attempt to rank formally the markets in terms of long-memory, fractal dimension, complexity, and informational inefficiency Table 3 presents a number of joint tests. The null hypotheses that the Hurst exponent and the informational inefficiency have been the same across all olive oil markets are not rejected at the conventional levels of significance. The null hypotheses, however, the fractal dimension, and the approximate entropy have been the same are rejected at the 5 and the 1 percent level of significance, respectively. Based on these findings one may conclude that differences in price dynamics among the principal olive oil markets in the EU stem largely from differences in their degrees of complexity.

As noted by Buccola (1984), informational inefficiency in food markets may arise from numerous sources including non-optimizing behavior, successful collusion, transaction costs, and informational disadvantage of buyers over sellers (or the other way round). The possession of market power may be relevant for the markets considered here since the blending and bottling of olive oil are carried out by a small number of (mainly) Italian firms. Fousekis (2022), in his study of risk transmission, found that olive oil prices in the leading olive oil markets of the EU were more likely to boom together than to crash together. Price stickiness is potentially a manifestation of market power.

Tab. 3. *Joint tests on the serial dependence measures and on the composite inefficiency index (all olive oil markets)*

[4] From Table 2, for example, the departure of prices in GR_XV from the ideal state for entropy is -0.495. Given that the expected value for *E* under full informational efficiency is 1, the estimate of *E* satisfies E-1=-0.495 implying that E=0.505; the departure of prices in IT_XV from the ideal state is -0.599, implying E=0.401.

Ho:	*p*-value
The long-range dependence is the same	0.104
The fractal dimension is the same	0.046
Entropy is the same	<0.01
Informational inefficiency is the same	0.161

Note: The *p*-values have been obtained using block-bootstrap (Politis and Romano, 1994) with 2500 replications.

***Tab. 4.** The contributions (shares) of different types of correlations to the composite efficiency index*

	Market					
Measure	IT_XV	IT_V	GR_XV	GR_V	SP_XV	SP_V
Long Range Dependence	0.043 (0.738)	0.042 (0.755)	0.446 (0.019)	0.611 (<0.01)	0.018 (0.858)	0.008 (0.936)
Fractal Dimension	0.296 (<0.01)	0.613 (<0.01)	0.058 (0.7)	0.009 (0.959)	0.087 (0.566)	0.192 (0.241)
Entropy	0.661 (<0.01)	0.345 (<0.01)	0.495 (0.012)	0.380 (0.047)	0.894 (<0.01)	0.799 (<0.01)

Notes:
(a) IT_XV, GR_XV, and SP_XV denote the extra-virgin olive oil markets in Italy, Greece, and Spain, respectively; IT_V, GR_V, and SP_V denote the virgin olive oil markets in Italy, Greece, and Spain, respectively.
(b) *p*-values in parentheses, obtained using block-bootstrap (Politis and Romano, 1994) with 2500 replications.

Table 4 shows the contributions (shares) of global, local, and complex correlations to informational inefficiency. The long-range dependence has had high and statistically significant contributions only for the Greek markets. The fractal dimension has had high and statistically significant contributions only in the Italian markets while entropy has had high and statistically significant contributions in all six markets. These results are in line with what has been already transpired from Table 2 and provide strong evidence that, for the majority of the markets considered, the lack of sufficient complexity of the price series is a much more important source of informational inefficiency relative to long-and short-range dependence.

Table 5 shows joint tests on the contributions to informational inefficiency. The null hypothesis that the share of long-range dependence has been the same is rejected at the 5 percent level. The null hypotheses, however, the contribution of short-range dependence and the contribution of entropy have been the same turned out to be consistent with the data. Kristoufek and Vosvrda, (2016) reported that the major source of informational inefficiency in the US gold and currencies futures markets was long-range dependence. Kristoufek (2018) found that complex correlations played a minor role in the informational efficiency of bitcoin markets relative to global and local correlations.

Tab. 5. *Joint tests on the contributions (shares) of different types of correlations to the composite efficiency index (all olive oil markets)*

Ho:	*p*-value
The share of long-range dependence is the same	0.034
The share of fractal dimension is the same	0.11
The share of entropy is the same	0.167

Note: The *p*-values have been obtained using block-bootstrap (Politis and Romano, 1994) with 2500 replications.

4. Conclusions

Informational efficiency of commodities markets is an integral part of economic efficiency and growth in a broader sense. In this context, the objective of the present work has been to investigate informational inefficiency in the principal olive oil markets of the EU. The empirical analysis relied on weekly national prices for extra-virgin and virgin olive oil in Spain, Italy, and Greece over 2017 and 2022 and a flexible approach that is capable of accommodating different types of serial correlation (long-memory, fractal dimension, and (lack of) complexity) and assessing the contribution of each type to a composite index of informational inefficiency.

On the basis of the empirical results, none of the six markets considered here has been fully informationally efficient. The markets of the leading producer (Spain), however, have attained somehow higher efficiency levels relative to those in Italy and Greece. The lack of sufficient complexity has been, in all cases, a sizable and statistically significant source of informational inefficiency. Long-range dependence has been relevant for informational inefficiency only for the Greek markets while local autocorrelation (fractal dimension) has been relevant only for the Italian virgin olive oil market. Overall, there have been both similarities and differences in the price dynamics across the six markets. The similarities may be attributed to the fact that olive oil of different quality produced in the same country as well as olive oil of the same or of different quality produced in geographically separated EU members are close substitutes; therefore, their prices are expected to co-move. The differences are likely to reflect special characteristics of a given market.

The ways to deal with informational efficiency naturally depend on its sources. If market power is a source, an intervention of competition authorities may be necessary. Articles 101 and 102 of the Treaty of the Function of the European Union (TFEU) focus on vertical and horizontal agreements and the exploitation of a dominant position, respectively whereas the EU Regulation 139/2004 addresses issues related to mergers. Informational disadvantages from the part of buyers or sellers, on the other hand, may be alleviated through the free provision of detailed information about prices, production, stocks, and other economic variables of interest. In this respect, the establishment (in 2012) of the Olive Oil Price Observatory by the International Olive Council has been a step in the right direction.

There are several promising avenues for future research. One may involve the use of rolling windows to investigate whether and how the autocorrelation patterns and the composite index change over time. The other may compare informational inefficiency and its components under positive and negative price shocks. In any case, additional work on this elaborate topic appears to be necessary.

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