




## Regular Article

Persistence in international prices of agricultural renewable commodities: a fractional integration approach<sup>☆</sup>Sakiru Adebola Solarin<sup>a</sup>, Carmen Lafuente<sup>b</sup>, Luis A. Gil-Alana<sup>c,b,\*</sup> ,  
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## ABSTRACT

In this work, we have examined historical data of renewable commodity prices by looking at the order of integration of the series from a fractional perspective. Using historical data from 1900 to 2022, we look at international prices of banana, cocoa, cotton, tea, hides, jute, lamb, coffee, maize, timber, beef, rubber, palm oil, rice, wheat, sugar, and wool. The empirical findings support the hypothesis of fractional integration and mean reversion in all cases, since the integration orders are all within the interval (0, 1). The lowest degree of persistence occurs in the cases of wheat, sugar, palm oil and maize, implying that shocks in these commodities disappear relatively fast. A unique break is permitted in the series and in most cases the break takes place during the 80s, and the only significant change in persistence is observed in lamb. A policy implication of the results is the need for buffer funds or buffer stock to decrease the impacts of volatility of the international agricultural renewable commodities on export returns.

## 1. Introduction

Agricultural renewable commodities are commodities that are materially replenishable over time or reused. These commodities include agricultural food commodities (such as bananas, wheat, coffee, sugar, maize, and beef) and agricultural non-food commodities (such as wool, timber, rubber, jute, hides and cotton) (Grilli and Yang, 1988; Gevorkyan, 2017; etc.). Agricultural renewable commodities (especially agricultural food components) are the most fundamental human need, and their availability is important for balanced social development (Gevorkyan, 2017). From a historical perception, agricultural renewable commodities, cultivated by peasant agrarians and arrogated by medieval aristocracies, were at the centre of early market exchange mechanisms (Karyotis & Alijani, 2016). The agricultural renewable commodities sector employs workers, serves as a source of raw materials and as a market for manufactured goods. Several developing economies rely on the export revenue from a single commodity, or, in some cases, few commodities (Abaidoo & Agyapong, 2022).

Several attributes of agricultural renewable commodities have been studied in the literature, usually alongside other agricultural commodities (Landajo & Presno, 2022). However, the persistence of renewable commodity prices has been grossly understudied in the literature. The examination of the renewable commodity prices persistence is valuable for a number of reasons. Persistence is associated with the random walk hypothesis or the weak form of the efficient market hypothesis, which implies that the current commodity price is reflective of all current information (Gil-Alana & Tripathy, 2014). Hence, the present market prices and future prices cannot be predicted using past information, by means of technical analysis and other related techniques. Another importance of persistence borders on the suitability of stabilisation policies on renewable commodity prices. Hedging and stabilisation strategies are more effective in addressing a price series that is trend stationary. This is because shocks arising from such prices will often be temporary. On the other hand, structural policies are needed for in the case of persistent prices as changes in such prices will be often permanent. The renewable commodity prices persistence also has

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consequences for the validity of the Prebisch–Singer hypothesis, which stipulates that primary commodities price decreases faster than the manufactured goods price. According to Landajo and Presno (2022), a requirement for the validity of the Prebisch–Singer hypothesis is the stationarity of the price of primary commodities as stationarity signals stability or equilibria in commodity markets, over time.

The main objective of this study is to examine the real international price persistence of 17 agricultural renewable commodities series during the period, 1900–2022. The two specific objectives of this study are (1) to introduce fractional integration in the examination of the persistence of agricultural renewable commodities; and (2) to examine the impact of structural breaks on the persistence of agricultural renewable commodities. The first null hypothesis associated with this study is “there is no persistence of agricultural renewable commodities” The second null hypothesis is “there is no persistence of agricultural renewable commodities in the presence of structural breaks” The study adds to the existing literature from three perspectives. First, we focus on a cluster of the primary agricultural commodity market - the renewable agricultural commodity market that have all the positive attributes of primary agricultural commodity markets. This cluster of the primary agricultural commodity market also has the added advantage of contributing less to environmental damage relative to the non-renewable agricultural commodity market. Second, we use a novel fractional integration approach that provides for structural breaks in the examination of the price of renewable commodities persistence. The use of fractional integration would seem to be a very suitable procedure to evaluate persistence, noting that it is more flexible and general than other methods that are based on integer differentiation orders. The provision for structural breaks is also necessary as commodity markets have undergone several economic shocks over the past century, including world wars, oil shocks, and economic recessions. Third, we use a lengthy time series in our analysis. By using 103 years of observations, the dependability of the empirical results is enhanced, and the persistence of renewable commodities can be evaluated over a lengthy period.

In addition, the analysis of renewable commodity price persistence is highly relevant in the current context due to the geopolitical tensions and persistent economic restrictions that have disrupted global supply chains and led to a decline in global demand. In this regard, natural resource markets are highly determined by political instability, international conflicts and various uncertain events, which significantly affect supply and demand dynamics, leading to price volatility and market instability (Zhao, 2023). From this perspective, understanding the persistence of renewable commodity prices is vital for developing effective policies and strategies.

The rest of the paper presents the following structure: Section 2 discusses the literature review. Section 3 focuses on the methodology, while Section 4 describes the dataset. Section 5 provides the empirical results and Section 6 sets out the discussion of the results, while Section 7 displays the conclusions.

## 2. Review of the literature

The long-term behaviour of commodity prices is a relevant issue in international and development economics (Winkelried, 2021). Understanding the volatility of these prices and their properties can have major consequences, especially for developing economies where primary commodities are their main source of export earnings (Fahmy, 2021; Ghoshray, 2021). Moreover, it is also important for investors in term of forecasting and risk management (Ghoshray, 2019).

Several studies have analyzed the connection between the dynamism of commodity prices and macroeconomic factors such as global economic activity (Delle Chiaie, Ferrara, & Giannone, 2022), inflation (Kyrtsov & Labys, 2006), trade policy (Sun et al., 2021), monetary policy (Hammoudeh et al., 2015; Siami-Namini et al., 2019), exchange rates (Alam & Gilbert, 2017), among others. On the other hand, commodity markets increasingly assume the role of financial assets

(Awaworyi-Churchill et al., 2022) and speculation in financial markets has led to spillovers in commodity markets. (Karyotis & Alijani, 2016).

The literature has prominently focused on the contributions of Prebisch (1950) and Singer (1950), which present empirical evidence of a downward trend in the prices of primary commodities in terms of manufactured goods during the period 1870–1945 (León & Soto, 1997; Newbold & Vougas, 1996). Studies such as that of Sapsford (1985), Grilli and Yang (1988), Helg (1991), León and Soto (1997), Harvey et al. (2010) among many others, support the validity of the Prebisch-Singer hypothesis. In contrast, Cuddington (1992) showed that this hypothesis is rejected using time series techniques to analyze 26 individual commodity prices over the period from 1900 to 1983. Likewise, Deaton and Laroque (2003) argued that the Prebisch-Singer hypothesis cannot be supported because the unit root tests generally lack statistical power.

Other studies such as Cuddington and Urzúa (1989) used time series techniques to the Grilli-Yang index of primary commodity prices and concluded that the price series has a unit root. These results are similar to the study by Barkoulas et al. (1997). The latter authors analyzed price series for 21 commodities traded on internationally markets using unit root tests and applying fractional integration methods. The results showed that in most cases the hypothesis of a unit root could not be rejected (nonstationarity) in the series under investigation. Newbold and Vougas (1996), on the other hand, suggested that the distinction between trend stationary and difference stationary is very imprecise.

In a related contribution, Awaworyi-Churchill et al. (2022) examined cycles and trends in commodity prices over seven centuries. These authors found that most commodity prices contained a unit root, suggesting that prices may not return to the long-run trend for extended periods of time.

With respect to the persistence of renewable commodities, Landajo and Presno (2022) analyzed trend stationary for a set of renewable commodities during the period 1900–2018, concluding that stationarity was rejected in half of the price series. By groups, these authors concluded that the series for livestock, coffee, tea, palm oil, and textile commodities are stationary, whereas those for rice, wheat, maize, cocoa, banana rubber and timber are nonstationary.

Likewise, Wang and Tomek (2007) showed that the effect of shocks on agricultural commodities is transitory. In the same line, Gil-Alana and Tripathy (2014) analyzed the presence of persistence in several primary commodity prices in India for the period 2003–2010. Using fractional integration, the results showed reversion to the mean in five of the series examined (rice, wheat, maize, bajra and jowar). By contrast, studies such as Goshray (2019) concluded that agricultural price shocks are permanent in nature.

Recent studies such as the work of Gil-Alana and Poza (2024) examined the persistence of volatility in the prices of nine major metals using monthly data from 1994 to 2023, employing fractional integration methods. The findings indicated that all metal price series are highly persistent, with limited mean reversion observed in gold and silver, while others exhibit more explosive volatility. Other related papers using similar methodologies to the one used in this work include Abakah et al. (2022) and Monge (2024).

On the other hand, studies such as Barunik and Vacha (2024) used a model to forecast the price volatility of major energy commodities such as crude oil, natural gas and gasoline. Caporale and Plastun (2024) employed the Hurst exponent to analyze the persistence in EuroStoxx 50 futures prices using high-frequency data over the period from 2002 to 2018. In a related study, Ahmed et al. (2024) used the Multifractal Detrended Cross-Correlation Analysis (MF-DCCA) method to analyze the nonlinear relationship and dynamic changes in multifractal behaviour between the Financial Stress Index (FSI) and four commodity indices: the Commodity Research Bureau Index (CRBI), the Baltic Dry Index (BDI), the London Metal Index (LME) and Brent oil prices (BROIL).

The foregoing literature review reveals that studies on renewable commodities are few and far between. The review also indicates that the use of fractional integration methods is rare among the price of

renewable commodities persistence papers. The only paper, [Gil-Alana and Tripathy \(2014\)](#), focussed on India using seven commodities. The results in India might not be relevant for other economies as countries have different structures and peculiarities. The use of seven commodities is insufficient as there are several renewable commodities and the result for one commodity might not always be generalizable to other commodities. The foregoing review also suggests that many of the papers on the persistence of primary agricultural commodity prices have used post-world wars datasets only.

### 3. Methodology

We apply a technique based on the concept of fractional integration, which allows us to perform fractional differentiation with respect to the integration order of the time series.

A given temporal series  $x(t)$ , where  $t = 1, 2, \dots$ , is said to be fractionally integrated or integrated of order  $d$  and denoted as  $I(d)$ , if it can be represented as:

$$(1 - B)^d x(t) = u(t), t = 1, 2, \dots \quad (1)$$

Here,  $B$  represents the backshift operator, i.e.,  $B^s x(t) = x(t-s)$ , and the term  $u(t)$  refers to an integrated process of order 0 or  $I(0)$ , defined as a second order stationary process with a positive and finite spectral density function,<sup>1</sup> also known as a short memory process. An alternative definition of  $I(0)$  in the time domain refers to a process where the infinite sum of autocovariances is finite. Within this category, we can mention the white noise process, and, the class of stationary and invertible autoregressive moving average (ARMA) models, which allow for weak autocorrelation. The origin of these processes is the 80s when [Granger \(1980\)](#), [Granger and Jouyeux \(1980\)](#) and others found that many aggregated economic series presented a periodogram with a large value around the smallest (zero) frequency, apparently requiring first differentiation; however, once the first differences were adopted, the new series displayed a periodogram with a value close to zero at the same zero frequency, which was a clear indication of over differentiation. [Robinson \(1978\)](#) and [Granger \(1980\)](#) justified them in terms of aggregation of heterogeneous processes. They became popular in econometrics in the late 90s, particularly after the groundbreaking work by [Gil-Alana and Robinson \(1997\)](#). In this study, these authors used a revised version of the famous [Nelson and Plosser's \(1982\)](#) dataset, which consist of fourteen macroeconomic time series for the US. These series were assumed to be integrated of order 1, incorporating a stochastic trend rather than a deterministic one. However, [Gil-Alana and Robinson \(1997\)](#) found that these series were better represented in terms of  $I(d)$  processes with  $d$  constrained between 0 and 1. Other studies also applied fractional integration in financial and economic data. Examples are [Abbritti et al. \(2016, 2023\)](#), [Zheng et al. \(2018\)](#) and [Yaya et al. \(2021\)](#).

The fact that the order of integration  $d$  may be a fractional value allows for a higher degree of flexibility in the dynamic specification of the model, and thus, it permits us to consider nonstationary processes though still with a mean reverting pattern, for example, if the order of integration is in the interval  $[0.5, 1)$ . Permitting  $d$  to be any real value makes the standard models for stationarity and unit roots to be considered as particular cases of interest with  $d = 0$  and 1 respectively. This is in fact the main justification for the use of the present approach. See [Gil-Alana and Hualde \(2009\)](#) and [Hualde and Nielsen \(2023\)](#) for interesting reviews of fractional integration models.

For the estimation and testing we use a very simple version of the tests of [Robinson \(1994\)](#) widely used in the analysis of fractional integration in macro and finance data (see, e.g., [Gil-Alana & Robinson, 1997](#)). This approach is very attractive since it is based on the Lagrange

Multiplier (LM) principle and thus uses the likelihood function, and it is valid for any real value  $d$ , including values outside the stationary region with no need for a priori differentiation of the data.

We conduct the estimation based on the following model:

$$y(t) = \beta_0 + \beta_1 t + x(t), (1 - B)^d x(t) = u(t), t = 1, 2, \dots \quad (2)$$

In this model,  $y(t)$  indicates the observed data;  $\beta_0$  and  $\beta_1$  are the coefficients corresponding to a constant and a linear time trend, and  $x(t)$  is a process that follows  $I(d)$  where  $d$  is another parameter estimated from the data. The differencing process  $u(t)$  is assumed to show weak autocorrelation according to [Bloomfield \(1973\)](#). The model of [Bloomfield \(1973\)](#) is considered a non-parametric description of the error term in the context of weak autocorrelation. It is non-parametric because it has not an explicit model, but it is implicitly expressed by means of its spectral density function,

$$f(\lambda; \sigma^2) = \frac{\sigma^2}{2\pi} \exp\left(2 \sum_{r=1}^m \tau_r \cos(\lambda r)\right), \quad (3)$$

where  $\sigma^2$  represents the variance of the error term and  $m$  is a parameter indicating the last of the Fourier frequencies. [Bloomfield \(1973\)](#) demonstrated that the logarithmic form of the spectral density function mentioned above provides a good approximation of the spectrum of autoregressive (AR) structures. Furthermore, this model is highly suitable in the context of fractional differentiation. An advantage of this model is that it is stationary across all values of  $\tau$  in (3) unlike what happens in the AR model, producing, however, an autocorrelation function which decays exponentially fast to zero as in the AR case. Based on (2), if  $d = 0$ ,  $y(t)$  follows the trend stationary representation advocated by authors such as [DeJong et al. \(1992\)](#) and others, while, if  $d = 1$ ,  $y(t)$  contains a unit root of the form proposed in [Dickey and Fuller \(1979\)](#), [Elliott, Rothenberg, and Stock \(1992\)](#) and others.

On the other hand, in recent years, various authors have claimed that non-linearities and breaks in the data may be responsible for the fractional structure of the data and that when these issues are taken into account, such a feature disappears from the data. Because of the long span of the data, in the empirical work carried out in the following section, structural breaks will also be taken into consideration, studying the degree of integration of different subsamples for each series. Thus, two hypotheses are tested in this work. The first null hypothesis is "there is no persistence of agricultural renewable commodities" The second null hypothesis is "there is no persistence of agricultural renewable commodities in the presence of structural breaks".

### 4. Data

We are working with data for real prices of 17 commodities for the period 1900–2022. The nominal annual prices for wheat (1900–2011), timber (1900–2018), rice, coffee, tea, lamb, maize, cocoa, sugar, palm oil, beef, banana, cotton, and rubber have been collected from both [Landajo and Presno \(2022\)](#) and the *Pink Sheet* of the World Bank. The nominal annual prices for jute have been collected from both [Landajo and Presno \(2022\)](#) and the *Statistical Bulletin* of Food and Agriculture Organization. The nominal annual prices for wool and hides have been collected from both [Landajo and Presno \(2022\)](#) and the *Primary Commodity Prices* of the International Monetary Fund. The base year is 1900 and the US consumer price index (as provided in <https://www.officialdata.org/us/inflation/1900?amount=1#overview>) has been employed to deflate the prices. Rice, palm oil, wheat, jute, and maize are in US dollar per metric ton. Hides are in US dollar per pound. The other series are in US dollar per kilogram. The details of the data sources have been provided in [Table 1](#).

[Table 2](#) displays the statistics and boxplots for the 17 commodities under study. It is observed that the boxes of the beef and lamb commodities are of greater amplitude than the rest, which indicates a higher

<sup>1</sup> The spectral density function is the Fourier transform of the autocovariances and is defined in the Interval  $[0, \pi)$ .

**Table 1**  
Data sources.

Series	Unit	Source
Banana	US\$ per kilogram	Landajo and Presno (2022) and the Pink Sheet of the World Bank
Beef	US\$ per kilogram	
Cocoa	US\$ per kilogram	Landajo and Presno (2022) and the Primary Commodity Prices of the International Monetary Fund
Coffee	US\$ per kilogram	
Cotton	US\$ per kilogram	Landajo and Presno (2022), Statistical Bulletin of Food and Agriculture Organization
Lamb	US\$ per kilogram	
Maize	US\$ per metric ton	Landajo and Presno (2022) and the Primary Commodity Prices of the International Monetary Fund
Palmoil	US\$ per metric ton	
Rice	US\$ per metric ton	Landajo and Presno (2022), Statistical Bulletin of Food and Agriculture Organization
Rubber	US\$ per kilogram	
Sugar	US\$ per kilogram	Landajo and Presno (2022) and the Primary Commodity Prices of the International Monetary Fund
Tea	US\$ per kilogram	
Timber	US\$ per kilogram	Landajo and Presno (2022), Statistical Bulletin of Food and Agriculture Organization
Wheat	US\$ per metric ton	
Hides	US\$ per pound	Landajo and Presno (2022) and the Primary Commodity Prices of the International Monetary Fund
Wool	US\$ per kilogram	
Jutes	US\$ per metric ton	Landajo and Presno (2022), Statistical Bulletin of Food and Agriculture Organization

\$ is dollars.

volatility in the real price indexes of these commodities with respect to the rest of the analyzed series. The beef and lamb series are the ones with the highest average real price indexes, above 2, the rest of the series, except timber which has an average value of 1.44, are below or very close to 1. This indicates that, on average, the real price indexes have decreased with respect to the reference year of the index (base 1900). Fig. 1 confirms this affirmation. All the series show a negative deterministic trend, except for beef, lamb and timbers, which show a positive trend and coffee which shows no apparent trend.

As we have already mentioned, the exploratory analysis of the 17 agricultural renewable commodity series, conducted through boxplots and descriptive statistics (mean, median, standard deviation, maximum, and minimum), has provided an initial insight into their distribution. Additionally, applying the Jarque-Bera (JB) test to assess data normality revealed that most series do not follow a normal distribution. Specifically, as shown in Table 2, only six of the 17 series (Banana, Cotton, Jute, Tea, Lamb and Wool) showed evidence of normality. For these six series, we could not reject the null hypothesis of normality given that their p-values were greater than the 0.05 significance level. This finding highlights the presence of skewness or kurtosis in the price distribution of most commodities studied, a common pattern in financial and raw material series. Despite the observed non-normality in the majority of the series, the fractional integration methodology used to evaluate persistence does not impose normality as a strict requirement for its application.

### 5. The results

The results reported across Table 3 are related with the estimate of the differencing parameter  $d$  in the model given by Equation (2) under the potential scenarios.

- i) with  $\beta_0$  and  $\beta_1$  being unknown and estimated along with  $d$ , (results displayed in column 4)
- ii) with  $\beta_1 = 0$  a priori, and thus, including an intercept in the model, (column 3) and
- iii) with both  $\beta_0$  and  $\beta_1$  equal to zero a priori, and thus including no (non-stochastic) terms in the first equality in Equation (2) (column 2).

We choose the best specification by testing with t-values the significance of the respective coefficients. Table 4 shows for each series the estimated coefficients of the selected models.

According to these results, the time trend model is required in all series except for banana and coffee. For these two cases, no intercept or trend is required. The estimates of the integration order  $d$  are in all cases in the interval (0, 1) supporting fractional integration and reversion to the mean. In Table 2 we observe that the lowest estimates of  $d$  correspond to wheat ( $d = 0.09$ ), sugar (0.19), palm oil (0.21) and maize (0.26). In fact, for wheat and sugar the  $I(0)$  hypothesis of short memory behaviour cannot be rejected. In all the other cases,  $d$  is found to be significantly positive, supporting long memory and persistence. Significant evidence of stationarity is only found in wheat and palm oil with all values in the confidence band strictly lower than 0.5. For all the other values, the confidence bands include values below and above 0.5, except for banana which seems to be nonstationary with all its values above 0.5. This commodity presents the highest degree of integration (0.74). Thus, in relation with the persistence of the data, the results reported so far decisively reject the hypothesis of no persistence in the agricultural renewable commodities. Looking at the time trend coefficients, they are positive for beef (0.0105), lamb (0.0129) and timber (0.0038); it is statistically insignificantly different from zero from banana and coffee, and significantly negative in the remaining cases.

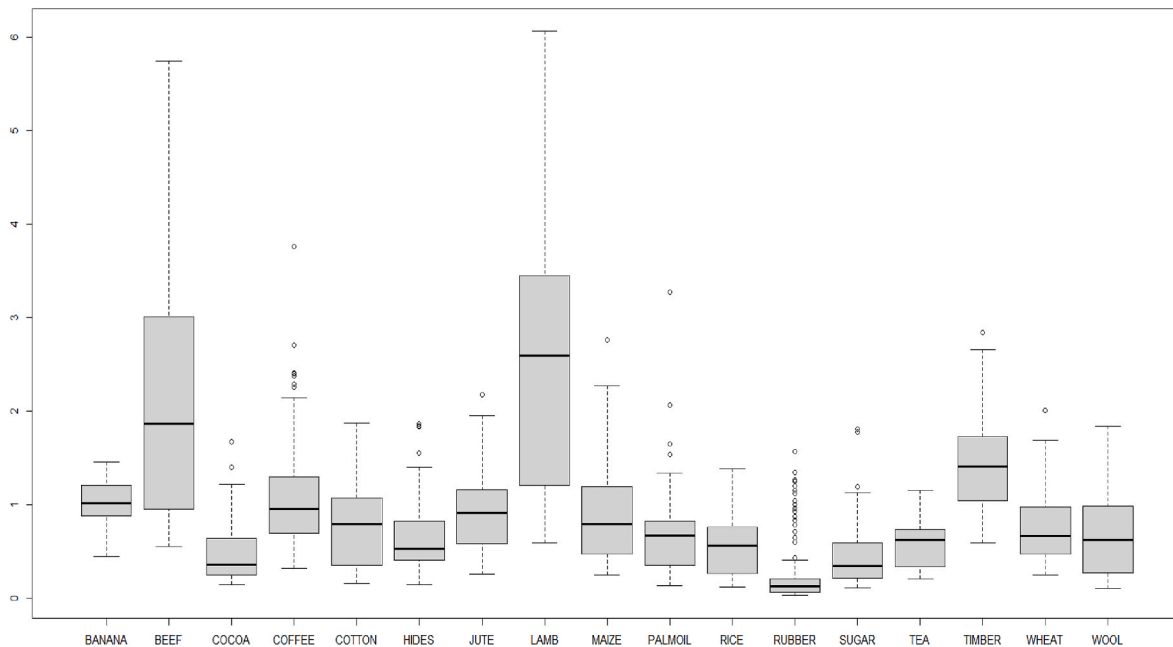
Next, we allow for breaks in the data. However, instead of permitting multiple breaks, we simply allow for a single one in each series, the reason being that multiple breaks would produce different subsamples with few observations in some cases, invalidating the analysis of fractional differentiation in a number of cases. The results, displayed in Table 5, indicate that the break occurs as early as in 1921 for rubber and in 1940 for timber; there are three commodities with breaks in the 50s: hides (1952) and beef and lamb (1959); for banana, the break takes place in 1968 and for wool in 1970. In all the other cases, the break occurs in the 80s.

Table 6 shows the estimates of  $d$  for the first subsamples, while Table 7 for the data after the break. In the two tables we have marked in bold the selected specification for each subsample, observing ten significant trends in the first subsamples, and 12 in the second ones. The results, in terms of  $d$ , vary substantially depending on the period examined and the series under examination. We observe that the confidence intervals are generally wide, and for beef and timber (in the first subsamples) and for coffee, sugar and tea (during the second subsamples) we cannot reject either the  $I(0)$  or the  $I(1)$  hypotheses. In the first subsamples, the  $I(0)$  or short memory hypothesis cannot be rejected for coffee, jute, maize, palm oil, rice, rubber, wheat and wool, while the only commodities where the  $I(1)$  or unit root hypothesis is not rejected in the first subsamples are hides and lamb.

For the data after the breaks, the short memory or  $I(0)$  hypothesis cannot be rejected for cocoa, cotton, hides, lamb, maize, palm oil, rice, rubber, timber, wheat or wool, and fractional integration and long memory (i.e.,  $d$  significantly above 0) occurs in the cases of banana, beef and jute. For these three commodities both  $I(0)$  and  $I(1)$  hypotheses are rejected at the 5 % level.

Table 8 summarizes the estimates of  $d$  for each series in the two subsamples. It is observed that there are seven commodities with an increase in the degree of integration: banana, jute, maize, rice, rubber, tea and wheat. However, there is only one series with a significant change from one subsample to the other. This is lamb which moves from 0.77 and where the  $I(1)$  hypothesis cannot be rejected to  $-0.20$  and

**Table 2**  
Descriptive statistics and boxplot of commodities.



BANANA	BEEF	COCOA	COFFEE	COTTON	HIDES
Min. :0.4445	Min. :0.5512	Min. :0.1404	Min. :0.3210	Min. :0.1628	Min. :0.1461
1st Qu.:0.8774	1st Qu.:0.9479	1st Qu.:0.2511	1st Qu.:0.6958	1st Qu.:0.3477	1st Qu.:0.4033
Median:1.0138	Median:1.8619	Median:0.3594	Median:0.9546	Median:0.7915	Median:0.5274
Mean:1.0327	Mean:2.0593	Mean:0.4687	Mean:1.0710	Mean:0.7572	Mean:0.6487
3rd Qu.:1.2100	3rd Qu.:3.0071	3rd Qu.:0.6374	3rd Qu.:1.2957	3rd Qu.:1.0741	3rd Qu.:0.8211
Max. :1.4570	Max. :5.7422	Max. :1.6709	Max. :3.7613	Max. :1.8732	Max. :1.8596
JB = 2.91, P = 0.23	JB = 11.73, p = 0.00	JB = 58.93, P = 0.00	JB = 148.42, P = 0.00	JB = 4.62, P = 0.10	JB = 57.62, P = 0.00
JUTE	LAMB	MAIZE	PALMOIL	RICE	RUBBER
Min. :0.2540	Min. :0.5932	Min. :0.2437	Min. :0.1389	Min. :0.1175	Min. :0.02777
1st Qu.:0.5862	1st Qu.:1.2079	1st Qu.:0.4678	1st Qu.:0.3544	1st Qu.:0.2657	1st Qu.:0.06666
Median:0.9150	Median:2.5915	Median:0.7945	Median:0.6743	Median:0.5565	Median 0.12444
Mean:0.9209	Mean:2.5326	Mean:0.8730	Mean:0.6651	Mean:0.5530	Mean:0.26041
3rd Qu.:1.1546	3rd Qu.:3.4441	3rd Qu.:1.1911	3rd Qu.:0.8197	3rd Qu.:0.7574	3rd Qu.:0.20862
Max. :2.1732	Max. :6.0612	Max. :2.7587	Max. :3.2693	Max. :1.3868	Max. :1.56993
JB = 5.56, P = 0.06	JB = 4.17, P = 0.12	JB = 24.68, P = 0.00	JB = 785.12, P = 0.00	JB = 6.38, P = 0.04	JB = 143.32, P = 0.00
SUGAR	TEA	TIMBER	WHEAT	WOOL	
Min. :0.1117	Min. :0.2111	Min. :0.5911	Min. :0.2497	Min. :0.1032	
1st Qu.:0.2151	1st Qu.:0.3339	1st Qu.:1.0382	1st Qu.:0.4734	1st Qu.:0.2699	
Median:0.3423	Median:0.6248	Median:1.4074	Median:0.6618	Median:0.6217	
Mean:0.4415	Mean:0.5737	Mean:1.4435	Mean:0.7510	Mean:0.6570	
3rd Qu.:0.5943	3rd Qu.:0.7364	3rd Qu.:1.7280	3rd Qu.:0.9739	3rd Qu.:0.9832	
Max. :1.8038	Max. :1.1520	Max. :2.8436	Max. :2.0052	Max. :1.8401	
JB = 136.47, P = 0.00	JB = 5.20, P = 0.07	JB = 9.53, P = 0.01	JB = 13.41, P = 0.00	JB = 5.60, P = 0.06	

where the I(0) null cannot be rejected. In all the other cases the confidence intervals overlap each other due to the wide intervals. Thus, in relation to the second hypothesis based on persistence in the data with breaks, the results are heterogeneous depending on the series under investigation.

**6. Discussion of the results**

The empirical results in the previous section indicate cases of reversion to the mean in the results. However, the degree of persistence has been increasing over time. The mean reversion evidence is in agreement with the result of Wang and Tomek (2007). Studies such as Ghoshray (2019), Awaworyi-Churchill et al. (2022), and Landajo and Presno (2022) have produced contrary results. A possible reason for the mean reverting nature of most of the prices of renewable commodities is

that their determinants are not persistent. According to Smyth (2013), a variable that is dependent on a (mean reverting) persistent series will imbibe such persistence (mean reversion). The usual determinants of prices of renewable commodities are the industrial production index and real effective exchange rates, and these are frequently stationary (Byrne et al., 2013).

Another possible reason for the lack of persistence in the series is that the mean of the prices has not drastically changed overtime. A persistent series often follows a stochastic process that does not have a consistent mean or distribution across time (Gujarati & Porter, 2010). For instance, the average real price for banana, jute, and timber was 1.10 US dollar per kilogram, 1.05 US dollar per metric ton, 0.90 US dollar per kilogram in 1900–1909, respectively. The average real price for banana, jute, and timber was 0.92 US dollar per kilogram, 1.04 US dollar per metric ton, and 1.35 US dollar per kilogram in 2010–2019, respectively. The

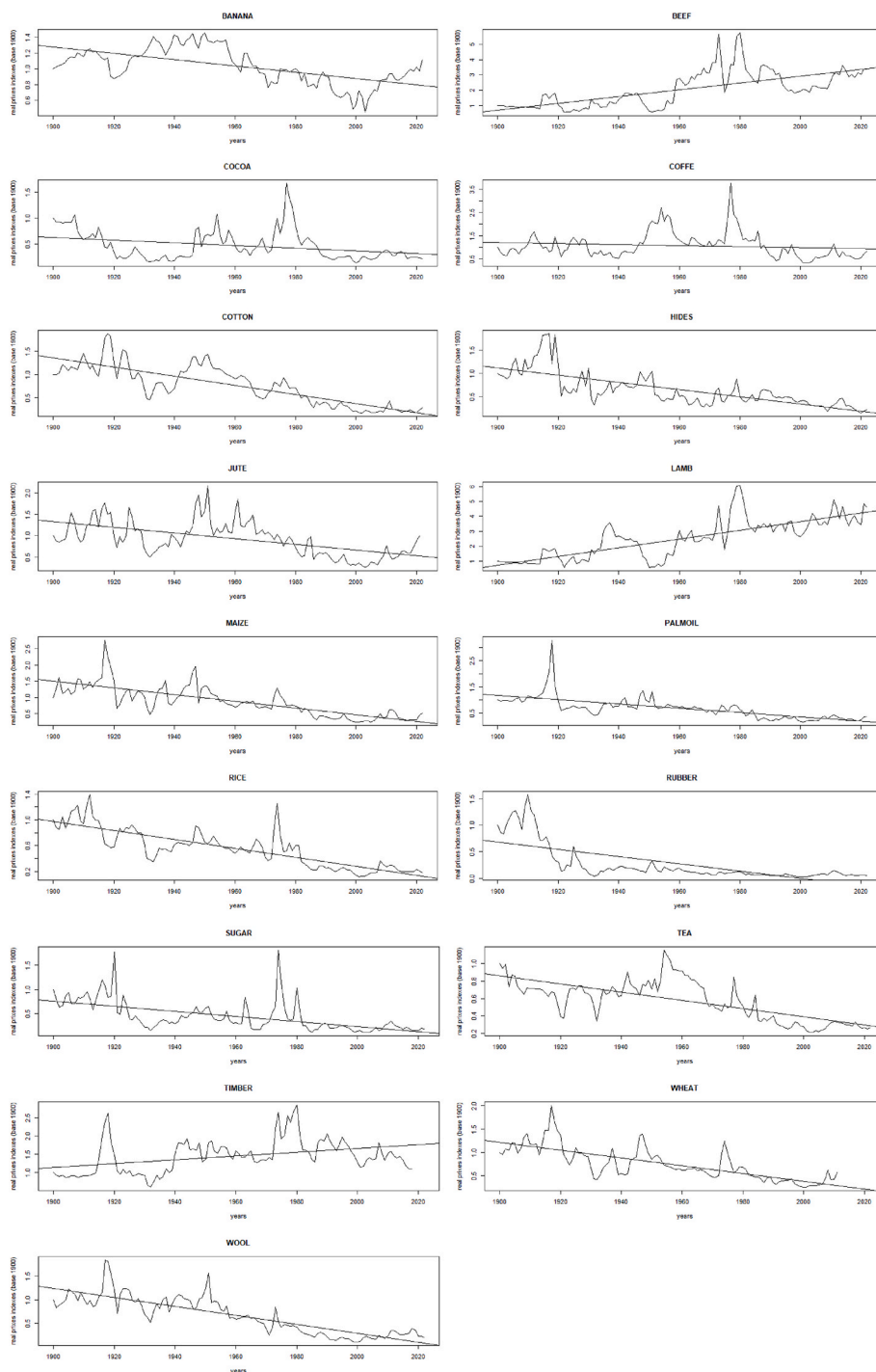


Fig. 1. Real prices indexes (deftated by US CPI, base 1900) of commodities.

average in the other intervals for each of the commodities are similar to the 1900–1909 and 2010–2019 intervals.

The use of real prices of renewable commodities as against nominal prices of renewable commodities can also be responsible for the mean reversion observed in the analysis. Unlike real prices, nominal prices tend to follow exponential growth rates over time (Baker et al., 2013). A series that experiences exponential growth is likely to be persistent, while a series that does not experience such growth over time is likely to be mean reverting (Gujarati & Porter, 2010).

The change in persistence witnessed in some of the commodities can be attributed to the change in the global exchange rate system. Greater price volatility is frequently experienced in the period of a floating

nominal exchange rates regime. The rise in real exchange rates in the post-Bretton Woods period triggered an increase in the commodity prices variability (Ghoshray, 2013). It has been established that persistent series are likely to be more volatile (Solarin et al., 2020).

The earlier part of the review period was characterised with the gold standard system and the Bretton Woods system. During the gold standard period, the value of a country’s currency was directly pegged to gold. The Bretton Woods system is a system where the country’s currency is pegged to the dollar, which in turn was directly pegged to gold. Both systems are forms of fixed exchange rates, which dominated the international economic system between 1900 and 1971. Since 1971, when the Bretton Woods system was ended, flexible exchange rate

**Table 3**  
Estimates of the differencing parameter in an I(d) Bloomfield autocorrelated model.

Series	No terms	An intercept	A linear time trend
Banana	<b>0.74 (0.57, 0.97)</b>	0.73 (0.56, 0.97)	0.72 (0.54, 0.97)
Beef	0.64 (0.45, 0.98)	0.65 (0.48, 0.98)	<b>0.63 (0.38, 0.98)</b>
Cocoa	0.50 (0.31, 0.73)	0.50 (0.31, 0.74)	<b>0.52 (0.32, 0.74)</b>
Coffee	<b>0.56 (0.37, 0.83)</b>	0.56 (0.37, 0.84)	0.55 (0.35, 0.84)
Cotton	0.56 (0.45, 0.71)	0.57 (0.47, 0.71)	<b>0.40 (0.24, 0.64)</b>
Hides	0.43 (0.29, 0.69)	0.47 (0.34, 0.69)	<b>0.27 (0.03, 0.66)</b>
Jutes	0.49 (0.36, 0.69)	0.51 (0.37, 0.69)	<b>0.41 (0.22, 0.68)</b>
Lamb	0.55 (0.36, 0.89)	0.57 (0.41, 0.89)	<b>0.52 (0.20, 0.88)</b>
Maize	0.51 (0.40, 0.70)	0.51 (0.41, 0.68)	<b>0.26 (0.04, 0.58)</b>
Palmoil	0.42 (0.32, 0.60)	0.47 (0.37, 0.61)	<b>0.21 (0.02, 0.49)</b>
Rice	0.44 (0.34, 0.61)	0.49 (0.40, 0.63)	<b>0.29 (0.09, 0.54)</b>
Rubber	0.51 (0.35, 0.79)	0.57 (0.46, 0.80)	<b>0.55 (0.36, 0.82)</b>
Sugar	0.30 (0.18, 0.55)	0.39 (0.26, 0.58)	<b>0.19 (-0.06, 0.53)</b>
Tea	0.58 (0.45, 0.76)	0.59 (0.47, 0.75)	<b>0.55 (0.40, 0.74)</b>
Timber	0.40 (0.22, 0.72)	0.44 (0.25, 0.72)	<b>0.40 (0.16, 0.73)</b>
Wheat	0.40 (0.27, 0.61)	0.45 (0.32, 0.63)	<b>0.09 (-0.16, 0.49)</b>
Wool	0.55 (0.46, 0.70)	0.58 (0.50, 0.71)	<b>0.42 (0.24, 0.64)</b>

The values in bold refers to the most adequate model in terms of the deterministic components.

**Table 4**  
Estimated coefficients based on the selected models.

Series	d (95 % band)	Intercept (tv)	Time trend (tv)
Banana	0.74 (0.57, 0.97)	–	–
Beef	0.63 (0.38, 0.98)	–0.0680 (–2.38)	0.0105 (2.73)
Cocoa	0.52 (0.32, 0.74)	–0.1992 (–2.13)	–0.0095 (–3.17)
Coffee	0.56 (0.37, 0.83)	–	–
Cotton	0.40 (0.24, 0.64)	0.3185 (3.10)	–0.0146 (–9.89)
Hides	0.27 (0.03, 0.66)	0.1625 (2.46)	–0.0121 (–8.11)
Jutes	0.41 (0.22, 0.68)	0.1403 (2.12)	–0.0060 (–3.31)
Lamb	0.52 (0.20, 0.88)	–0.0578 (–2.39)	0.0129 (4.61)
Maize	0.26 (0.04, 0.58)	0.4499 (4.90)	–0.0123 (–9.97)
Palmoil	0.21 (0.02, 0.49)	0.2295 (2.73)	–0.0133 (–11.80)
Rice	0.29 (0.09, 0.54)	0.1070 (2.17)	–0.0143 (–11.61)
Rubber	0.55 (0.36, 0.82)	–0.0866 (–2.39)	–0.0249 (–6.26)
Sugar	0.19 (–0.06, 0.53)	–0.2158 (–1.87)	–0.0130 (–8.45)
Tea	0.55 (0.40, 0.74)	–0.0597 (–2.51)	–0.0100 (–4.76)
Timber	0.40 (0.16, 0.73)	0.0144 (2.17)	0.0038 (3.09)
Wheat	0.09 (–0.16, 0.49)	0.2623 (5.49)	–0.0117 (–16.39)
Wool	0.42 (0.24, 0.64)	0.1970 (2.49)	–0.0148 (–7.62)

Column 2 refers to the estimates of the differencing parameter and the 95 % confidence band; column 3 reports the value of the constant and its t-value; column 4 the time trend coefficient and its t-value.

**Table 5**  
Break date for each series using Bai and Perron (1998, 2003).

Series	Break date	Series	Break date
Banana	1968	PALMOIL	1985
Beef	1959	RICE	1982
Cocoa	1989	RUBBER	1921
Coffee	1989	SUGAR	1982
Cotton	1985	TEA	1985
Hides	1952	TIMBER	1940
Jutes	1980	WHEAT	1982
Lamb	1959	WOOL	1970
Maize	1982		

We tested the null of no structural breaks against the alternative hypothesis of one break using the sequential test in Bai and Perron (1998, 2003).

systems have dominated the international economy.

### 7. Concluding comments

Historical data of agricultural renewable commodity prices have been examined in this paper by looking at the integration order of the

**Table 6**  
Estimates of the differencing parameter in an I(d) Bloomfield autocorrelated model. First subsamples.

Series	No terms	An intercept	A linear time trend
Banana	0.48 (0.21, 0.92)	<b>0.54 (0.26, 0.92)</b>	0.51 (0.20, 0.92)
Beef	<b>0.52 (-0.07, 1.37)</b>	0.52 (–0.08, 1.41)	0.53 (–0.11, 1.40)
Cocoa	0.51 (0.31, 0.78)	<b>0.49 (0.30, 0.76)</b>	0.52 (0.32, 0.78)
Coffee	0.41 (0.16, 0.79)	0.41 (0.17) 0.81	<b>0.35 (0.03) 0.77)</b>
Cotton	0.14 (–0.03, 0.42)	0.15 (–0.03, 0.43)	<b>0.06 (-0.37, 0.44)</b>
Hides	<b>0.54 (0.23, 1.10)</b>	0.54 (0.24, 1.10)	0.48 (–0.25, 1.10)
Jutes	0.16 (–0.14, 0.57)	<b>0.16 (-0.15, 0.58)</b>	0.16 (–0.15, 0.58)
Lamb	<b>0.77 (0.38, 1.40)</b>	0.77 (0.40, 1.40)	0.78 (0.38, 1.36)
Maize	0.21 (0.02, 0.49)	0.20 (0.02, 0.46)	–0.12 (–0.48, 0.33)
Palmoil	0.21 (0.02, 0.57)	0.23 (0.02, 0.55)	<b>0.12 (-0.20, 0.56)</b>
Rice	0.09 (–0.03, 0.28)	0.12 (–0.04, 0.35)	–0.02 (–0.23, 0.29)
Rubber	–0.24 (–0.97, 0.73)	–0.21 (–0.98, 0.76)	–0.23 (–0.96, 0.63)
Sugar	0.27 (0.08, 0.58)	0.30 (0.11, 0.59)	<b>0.27 (0.04, 0.58)</b>
Tea	0.41 (–0.03, 0.73)	0.27 (–0.01, 0.68)	<b>0.41 (0.10, 0.73)</b>
Timber	<b>0.38 (-0.10, 1.10)</b>	0.37 (–0.09, 1.10)	0.38 (–0.15, 1.10)
Wheat	0.25 (0.07, 0.53)	0.28 (0.10, 0.55)	–0.05 (–0.38, 0.40)
Wool	0.38 (0.12, 0.77)	0.39 (0.12, 0.78)	<b>0.29 (-0.09, 0.72)</b>

**Table 7**  
Estimates of the differencing parameter in an I(d) Bloomfield autocorrelated model. Second subsamples.

Series	d (95 % band)	Intercept (tv)	Time trend (tv)
Banana	<b>0.57 (0.27, 0.91)</b>	0.57 (0.29, 0.93)	0.57 (0.28, 0.93)
Beef	0.58 (0.32, 0.89)	<b>0.35 (0.07, 0.86)</b>	0.44 (0.02, 0.87)
Cocoa	0.39 (–0.43, 0.97)	–0.08 (–0.52, 0.40)	–0.41 (–0.86, 0.47)
Coffee	0.14 (–0.17, 1.26)	0.23 (–0.28, 1.13)	<b>0.26 (-0.46, 1.17)</b>
Cotton	0.05 (–0.08, 0.23)	0.17 (–0.20, 0.52)	–0.11 (–0.48, 0.40)
Hides	0.37 (0.04, 0.70)	0.28 (0.04, 0.60)	<b>0.27 (-0.01, 0.66)</b>
Jutes	0.26 (0.01, 0.64)	<b>0.34 (0.02, 0.67)</b>	0.34 (0.01, 0.66)
Lamb	–0.02 (–0.10, 0.09)	–0.06 (–0.30, 0.25)	–0.20 (–0.47, 0.19)
Maize	0.11 (–0.06, 0.64)	0.30 (–0.16, 0.79)	<b>0.26 (-0.24, 0.79)</b>
Palmoil	–0.18 (–0.37, 0.59)	–0.74 (–1.06, 0.01)	–0.58 (–0.89, 0.01)
Rice	0.73 (–0.12, 1.41)	0.28 (–0.20, 1.53)	<b>0.69 (-0.12, 1.44)</b>
Rubber	0.27 (0.15, 0.72)	0.45 (0.32, 0.69)	<b>0.28 (-0.02, 0.68)</b>
Sugar	0.42 (–0.19, 1.17)	–0.02 (–0.46, 1.16)	0.03 (–0.44, 1.21)
Tea	0.47 (–0.11, 1.03)	0.23 (–0.19, 1.06)	<b>0.52 (-0.10, 1.08)</b>
Timber	0.13 (–0.07, 0.60)	0.17 (–0.16, 0.57)	<b>0.18 (-0.13, 0.56)</b>
Wheat	0.04 (–0.14, 0.83)	0.15 (–0.43, 0.71)	<b>0.01 (-0.92, 0.72)</b>
Wool	0.17 (0.04, 0.60)	0.30 (0.10, 0.53)	<b>0.25 (-0.02, 0.54)</b>

**Table 8**  
Selected estimates for each subsample.

Series	First subsample	Second subsample
Banana	0.54 (0.26, 0.92)	0.57 (0.27, 0.91)
Beef	0.52 (–0.07, 1.37) <sup>a,b</sup>	0.35 (0.07, 0.86)
Cocoa	0.49 (0.30, 0.76)	–0.41 (–0.86, 0.47) <sup>a</sup>
Coffee	0.35 (0.03, 0.77)	0.26 (–0.46, 1.17) <sup>a,b</sup>
Cotton	0.06 (–0.37, 0.44) <sup>a</sup>	–0.11 (–0.48, 0.40) <sup>a</sup>
Hides	0.54 (0.23, 1.10) <sup>b</sup>	0.27 (–0.01, 0.66) <sup>a</sup>
Jutes	0.16 (–0.15, 0.58) <sup>a</sup>	0.34 (0.02, 0.67)
Lamb	0.77 (0.38, 1.40) <sup>b</sup>	–0.20 (–0.47, 0.19) <sup>a</sup>
Maize	–0.12 (–0.48, 0.33) <sup>a</sup>	0.26 (–0.24, 0.79) <sup>a</sup>
Palmoil	0.12 (–0.20, 0.56) <sup>a</sup>	–0.74 (–1.06, 0.01) <sup>a</sup>
Rice	–0.02 (–0.23, 0.29) <sup>a</sup>	0.69 (–0.12, 1.44) <sup>a</sup>
Rubber	–0.23 (–0.96, 0.63) <sup>a</sup>	0.28 (–0.02, 0.68) <sup>a</sup>
Sugar	0.27 (0.04, 0.58)	–0.02 (–0.46, 1.16) <sup>a,b</sup>
Tea	0.41 (0.10, 0.73)	0.52 (–0.10, 1.08) <sup>a,b</sup>
Timber	0.38 (–0.10, 1.10) <sup>a,b</sup>	0.18 (–0.13, 0.56) <sup>a</sup>
Wheat	–0.05 (–0.38, 0.40) <sup>a</sup>	0.01 (–0.92, 0.72) <sup>a</sup>
Wool	0.29 (–0.09, 0.72) <sup>a</sup>	0.25 (–0.02, 0.54) <sup>a</sup>

<sup>a</sup> Indicates evidence of I(0), while b supports I(1) at the 95 % level.

series using long memory fractionally integrated models. Using data of real price indexes of 17 commodities (banana, coffee, beef, cocoa, rubber, lamb, maize, oil, hides, palm, rice, cotton, sugar, jute, timber, wheat, tea, and wool), for the time period 1900–2022, our results

indicate supporting evidence of fractional integration and reversion to the mean in all cases, since the integration orders of the series are in the interval (0, 1). The lowest degree of dependence take place in the cases of wheat, sugar, palm oil and maize, implying that shocks in these commodities disappear relatively fast. On the other extreme, banana displays the highest degree of integration with a value significantly above 0.5 and thus implying nonstationary, though with a mean reverting, rather slow, pattern. Allowing for a break in the data, which occurs in most of the cases during the 80s, though in some cases it takes place as early as 1921 (rubber), 1940 (timber) and during the 50s for hides, beef and lamb. Looking at the integration orders during the subsamples, the confidence intervals are generally wide, and in some cases we cannot reject either the I(0) or the I(1) hypothesis (for example for beef and timber in the first subsamples and for coffee, sugar and tea during the second subsamples). Comparing the two subsamples, there is an increase in the level of persistence in seven commodities: banana, jute, maize, rice, rubber, tea, and wheat.

The foregoing results suggest that shocks associated with the prices of agricultural renewable commodities are characteristically short-lived which has an implication for developing countries that earn their export revenues from a reduced number of commodities. In these countries, changes to international borrowing and lending or domestic savings to smooth the path of national consumption is possible in the event of negative shocks arising from sudden changes in the prices of renewable commodities. Price stabilisation schemes including buffer funds or buffer stock may be employed to decrease the impacts of volatility of international agricultural renewable commodities on export returns. This would be especially applicable for countries including Thailand which depends on its exports of rubber and rice; and Uganda, Ethiopia, and Burundi, which are profoundly reliant on their export earnings from coffee; and for the Sri Lanka, which depend on its exports of tea. The foregoing results also suggest that the market power of the producers on the real prices of renewable commodities is limited. This is because any attempt to change prices without any change in the market fundamentals might not last for a very long time.

Overbearing structural policies, (which are long term in nature and often involve long term commitments) by importing nations to cope with sudden increases in prices of renewable commodities might not be needed in all cases, except when the changes are very significant. Structural policies such as heavy investment in storage facilities to ensure better security of supply; involvement in long term price agreements with exporting nations to commodities at a fixed price irrespective of future situation are frequently meant for commodities with persistent prices series as the shocks emanating from such prices will often be permanent.

Another implication of the results is that it is feasible to accurately forecast future prices of renewable commodities series using the past behaviour of the series. Therefore, spot prices can be used as a basis of formulating future prices. In other words, spot prices can play a central role in the future or forward markets of the renewable commodities. To avoid manipulation, abusive and cheating practices in the sales of commodities in the future markets, it is recommended that clauses that require current and past prices to play central roles in the transactions should be added.

There are certain limitations associated with this paper. First, the data frequency employed in this work could be changed to other frequencies such as quarterly or monthly to see if the results are robust to these changes. We have only considered international prices of renewable commodities. With availability of the relevant data in the future, subsequent studies could also analyze the persistence of local prices of renewable commodities and evaluate the relationship between international prices and local prices of renewable commodities. The convergence of the international prices of renewable commodities can be considered by future studies. Analysing the convergence of the series would shed light on whether joint policy or commodity-specific policy is needed to tackle undesirable changes in the prices of renewable

commodities.

### CRediT authorship contribution statement

**Sakiru Adebola Solarin:** Writing – original draft, Supervision, Investigation, Formal analysis. **Carmen Lafuente:** Writing – review & editing, Visualization, Formal analysis, Data curation, Conceptualization. **Luis A. Gil-Alana:** Software, Methodology, Investigation, Formal analysis. **María Jesús González-Blanch:** Writing – original draft, Resources, Data curation, Conceptualization.

### Ethical statement

There are no ethical issues with the publication of the present manuscript.

### Declaration of the use of AI

We have not used AI for any part of the work related to the manuscript submitted.

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### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data used in this paper are available from the authors upon request.

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