Postprint of: Potrykus M., Price bubbles in commodity market – A single time series and panel data analysis, QUARTERLY REVIEW OF ECONOMICS AND FINANCE Vol. 87 (2023), pp. 110-117, DOI: 10.1016/j.qref.2022.12.002

Price bubbles in commodity market – a single time series and panel data analysis

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Abstract:

This paper examines thirty-five commodities, grouped into three market sectors (energy, metals, agriculture & livestock) in terms of the occurrence of price bubbles. The study was based on monthly data for each commodity separately and, in a panel approach, for selected sectors and for all commodities combined. The GSADF test and its version for panel data – panel GSADF – were used to identify bubbles. The beginning and end of the detected price bubbles were also determined.

No price bubbles were found for commodities such as Bananas, Cocoa or Orange juice, while tin, tobacco and gold were identified as the commodities most prone to bubbles. Also, a distinction was made between those commodities characterized by short and infrequent periods of price bubbles (five commodities) and those characterized by frequent and usually lasting for at least six months periods of bubbles (eighteen commodities). The panel confirmed that the energy and metals sectors are exposed to periods of bubbles more frequently and for longer than the agriculture & livestock sector. For all identified panels, a clear impact of the financial crisis of 2008 and the European debt crisis on the emergence of commodity bubbles was found.

Keywords: Commodities price bubble, Generalized supremum ADF, panel data analysis

Classification codes: E3, Q02

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest: none

1. Introduction

Numerous studies have been devoted to the formation of price bubbles in recent years, covering not only capital markets (Basse et al., 2021; Chen et al., 2021; Cheng et al., 2021; Feng & Wu, 2015; Gilchrist et al., 2005; Hu & Oxley, 2018; Narayan et al., 2013) but also commodity markets. A list of the more important papers prepared within the last ten years and devoted to the analysis of bubbles in commodity markets is presented in Table 1. Nevertheless, there are still numerous research gaps in this field, and this study aims to fill the selected ones.

Firstly, studies to date have mainly focused on single commodities or only on several commodities. Thirty-five commodities, grouped into three market sectors, are examined in this article, which constitute an unprecedented number of data series. Secondly, the survey was conducted for each commodity individually and using panel data based on pre-defined market sectors. The use of the panel data approach and test are an added value of this study, which is rarely seen in studies to date. This approach makes it possible to examine the wide commodity market. Thirdly, the study covers a long period from January 1980 to December 2021, i.e. 504 observations for each data series examined. This is one of the longer study periods analysed to date for such a large number of commodities. Fourthly, the study also examines twenty-two commodities from the agriculture & livestock sector, which, as shown in this article, have failed to attract much attention from researchers to date.

The conclusions of this study, with the continuing unabated role of commodities in the world, should prove valuable to commodity market analysts, both individual and institutional investors, companies and policymakers because apart from assessing whether bubbles occur for a given market, their beginning and end were also determined.

In the remainder of this paper, a literature review focused on commodity price bubbles is presented in Section 2. Section 3 presents the research methodology and data used for the analysis, while the next section contains the results from the survey, which are summarised in Section 5.

2. Literature review

Numerous academic studies have been devoted to the issue of bubbles in the commodity market recently. A summary of these studies detailing the commodities involved, and the research methods used, is presented in Table 1. However, it did not include studies presented before 2012. This is to ensure that the literature review presented in the table does not duplicate results from previous studies, but focuses on current studies on bubbles in the commodity market. The results in Table 1 are presented chronologically.

Table 1 Summary of key academic studies on commodity price bubbles.

No.	Article	Commodity	Research method	Identified bubbles	Research period
1	(Lucey & O'Connor, 2013)	Gold	ADF test, cointegration test, Markov switching ADF	Depends on research method, ADF test and cointegration test – Yes, Markov switching ADF – Yes/No	17 July 1989 to 31 July 2013, daily
2	(Balcilar et al., 2014)	Crude oil	"exponential fitting" methodology	Yes	20 May 1987 to 9 July 2013 for Brent, for WTI, it starts on 2 January 1986, daily
3	(Białkowski et al., 2015)	Gold	Markov regime-switching ADF	Gold – Yes, but results are sensitive to the specification of the fundamental value	January 1975 to June 2013, monthly
4	(El Montasser et al., 2015)	Ethanol-petrol price ratio	ADF, SADF, GSADF	Yes	2000 to 2012, monthly
5	(Adämmer & Bohl, 2015)	Corn, soybean, wheat	MTAR	Wheat – Yes, Corn, soybean – Yes/No	January 1993 to December 2012, monthly
6	(Fantazzini, 2016)	Crude oil	GSADF and LPPL	Yes (negative bubble)	January 2013 to April 2015, daily
7	(Y. J. Zhang & Yao, 2016)	Crude oil, diesel, petrol	State-space model and LPPL	Crude oil - yes, diesel – yes, petrol - no	1 November 2001 to 21 December

					2015, daily
8	(Su et al., 2017)	Iron ore	GSADF	Yes	January 1980 – December 2-16, monthly
9	(D. Zhang et al., 2018)	Crude oil, Natural gas	GSADF	Crude oil – Yes Natural gas - Yes	January 1982 to October 2017, monthly
10	(Sharma & Escobari, 2018)	Indices: Crude oil, heating oil, natural gas; Spot prices: WTI, Brent, heating oil, natural gas, jet fuel	SADF and GSADF	Yes – in all analysed series	Beginning depends on time series, mainly starts from 1990s and ends for all series on 25 December 2015, weekly
11	(Pan, 2018)	Gold, silver	ADF, SADF, GSADF	SADF and GSADF – Yes, ADF - No	January 1990 to October 2017, monthly
12	(Li et al., 2020)	Natural gas (US, European and Asian market)	GSADF	Yes	January 1996 to June 2017, monthly
13	(Khan & Derindere Köseoğlu, 2020)	Palladium	GSADF	Yes	January 1994 to January 2020, monthly
14	(Su et al., 2020)	Copper	GSADF	Yes	January 1980 to May 2019, monthly
15	(Mao et al., 2021)	Corn, Soybean	GSADF	Corn - YES, Soybean - Yes	2006 to 2017, daily

16	(Khan, Su, & Rehman, 2021)	Coal	SADF and GSADF	Yes	January 1971 to November 2020, monthly
17	(Khan, Su, Umar, et al., 2021)	Crude oil	GSADF	Yes	January 2000 to July 2020, monthly
18	(Ajmi et al., 2021)	WTI, Brent, Dubai	Double recursive algorithm (extension of) SADF and GSADF	Yes – in all analysed series	January 1982 to October 2020, monthly
19	(Ozgur et al., 2021)	Gold, palladium, platinum, rhodium, silver, aluminium, copper, lead, nickel, steel, tin	GSADF	Silver, aluminium, tin – No, Yes, in the remaining metals	January 1980 to December 2019, monthly
20	(Wahab & Adewuyi, 2021)	Gold, silver, platinum, palladium, copper	GSADF	Yes - in all analysed series	1990-2021, daily and weekly
21	(Khan et al., 2022)	Brent, WTI, coal, natural gas (2 series), heating oil	SADF, GSADF	Yes – in all analysed series	January 2000 to August 2021, monthly
22	(Oladosu, 2022)	Petrol prices (10 US cities)	GSADF	Yes	2000-2017, weekly

Source: Authors' own elaboration.

Based on the literature review in the context of commodity price bubbles, it can be seen that the predominant method for determining the examined phenomenon is the GSADF test, which was used in seventeen of the twenty-two papers listed in Table 1. Therefore, the same test was used in this study. The theoretical basis of this test and its modified panel version are presented in the next section of the paper, in the methodological part. Moreover, the most common commodities tested for the occurrence of price bubbles were crude oil (eight studies) as well as gold and natural gas (five studies each). Investments belonging to the agriculture & livestock sector are of less interest to researchers. The highest number of major commodities analysed in a single study was eleven (Ozgur et al., 2021), and thirteen papers focused on a single commodity, noting here that in several papers, for example (Li et al., 2020; Oladosu, 2022; Sharma & Escobari, 2018), more than one data series was used for such analysis. The fact of using data with a monthly frequency (in fifteen studies) and the confirmation of the occurrence of price bubbles on the examined commodity markets is also dominant in the light of the listed studies.

Only five (Adämmer & Bohl, 2015; Lucey & O'Connor, 2013; Ozgur et al., 2021; Pan, 2018; Y. J. Zhang & Yao, 2016) of the studies did not confirm the existence of price bubbles under the research assumptions or indicated that the result was inconclusive. Such results were obtained for gold, corn, soybean, petrol and silver, but these studies, except for (Ozgur et al., 2021), did not apply GSADF as a research method. In contrast, the study (Ozgur et al., 2021) indicated silver, aluminium and tin as those with no existence of bubbles using the GSADF test. However, critical values for this test were obtained using the bootstrap method with a repetition rate of 2,000. An interesting research approach was also applied in the study (Sharma & Escobari, 2018), where in addition to examining individual commodities, analysis was also performed for indices representing crude oil, heating oil and natural gas.

3. Methodology and data

To determine bubbles, this study uses the rational bubble theory mainly presented in (Diba & Grossman, 1988) and adapted for the commodity market in (Pindyck, 1993). Based on the studies presented above, the price of any commodity (more broadly any asset) at time "t" (P_t) can be written as the following sum (Pan, 2018):

$$P_t = P_t^f + B_t$$

Where,

$P_t^f - is\ fundamental\ component, fundamental\ price$

$B_t - is\ bubble\ component, bubble\ factor$

If $B_t \neq 0$, there is a bubble on the market of a given commodity (Campbell et al., 2012). It should be noted here that the value of the bubble factor is defined as:

$$B_t = E_t\left[\frac{B_{t+1}}{1+r}\right]$$

and is different from zero only if market participants also expect it to occur and to worsen in the following period (B_{t+1}), even after taking into account a discount factor equal to (1+r), where r is the assumed rate of return.

To detect bubbles as defined above, this study uses the Generalized Supremum Augmented Dickey-Fuller (GSADF) methodology presented in (Phillips et al., 2015). This test was chosen because it was more effective than other tests used to identify bubbles (Li et al., 2020) that contributed to the development of the GSADF test such as the SADF test, the Supremum Augmented Dickey-Fuller test (Phillips et al., 2011) or the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979). As highlighted in the study (Khan, Su, & Rehman, 2021), the GSADF test does not lose its power when the time series analysed is long and there is more than one bubble, which is important in the context of the long study period adopted in this paper.

The GSADF test statistic is defined as follows:

$$GSADF(r_0) = \sup_{r_2 \in [r_0, 1], r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2}$$

Where:

r_0 - minimum length of the test window,

r_1 - start of the test window,

r_2 - end of the test window,

ADF - the value of the statistic for a "standard" ADF test.

The value of the test statistic constructed in this way considers not only the change at the end point of the test, but also different values for the beginning of the test window (Su et al., 2020). A graphical interpretation related to the flexible start and end of the test window in the GSADF procedure is presented, for example, in (Caspi, 2017). Bubbles occur when the value of the GSADF test statistic is greater than the critical value of the test obtained from, for example, the Monte Carlo simulation or the bootstrap method. If the value of the GSADF test is less than the obtained critical value for the test, there are no grounds for rejecting the null hypothesis of no bubbles for the analysed data series. If bubbles are identified for the analysed time series, in the next step, using the backward SADF (BSADF) test, the date stamp for the identified bubbles can be determined, which was also determined in this paper. This procedure is also described in (Phillips et al., 2015), and the formula for this test is as follows (Hu & Oxley, 2018):

$$BSADF_{r_2}(r_0) = \sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2}$$

In this study, following the examination of the individual data series for the analysed commodities, the analysis was also conducted for panel data and the procedure for testing and date-stamping price bubbles defined in (Vasilopoulos, Pavlidis, & Martínez-García, 2020) was applied. According to the authors of this paper, in this procedure the critical test values are calculated using the sieve bootstrap method, which is designed to allow for cross-sectional error dependence. The value of the panel GSADF test statistic (panel GSADF test) and the value of the panel BSADF test statistic, used to determine the temporal occurrence of bubbles, for N time series were described as (Vasilopoulos, Pavlidis, & Martínez-García, 2020):

$$PGSADF(r_0) = \sup_{r_2 \in [r_0, 1]} PBSADF_{r_2}(r_0)$$

$$PBSADF_{r_2}(r_0) = \frac{1}{N} \sum_{i=1}^{N} BSADF_{i,r_2}(r_0)$$

The experiment designed in this way will make it possible to determine not only the occurrence of bubbles for individual investments in commodities, but also for the entire commodity market understood as a whole or in a sectoral approach.

The data used for the analysis come from the World Bank (*Commodity Markets* "Pink sheet", 2022) and cover the three most important sectors of the commodity market, namely energy, metals and agriculture & livestock (*DOW JONES COMMODITY INDEX Index Attributes*, 2022). The article analyses the prices of thirty-five commodities such as:

- agriculture & livestock sector: Banana, Beef, Cocoa, Coconut oil, Coffee, Cotton, Fish meal, Groundnuts, Logs, Maize, Chicken meat, Orange, Palm oil, Plywood, Rice, Sawnwood, Shrimps, Soybeans, Sugar, Tea, Tobacco, Wheat.
- energy sector: Coal, Crude oil, Natural gas.
- metals sector: Aluminium, Copper, Gold, Iron ore, Lead, Nickel, Platinum, Silver, Tin, Zinc.

For the commodities listed above, the analysis used monthly data from January 1980 to December 2021, i.e. 504 observations for each data series. All calculations were performed in R using the exuber v.0.4.2 package (Vasilopoulos, Pavlidis, Spavound, et al., 2020).

4. Research results

First, during the test, the value of GSADF test statistics was calculated for all thirty-five commodities. The values of these statistics were then compared with the calculated critical values of the test, which were obtained by means of the Monte Carlo simulation with a repetition rate of 10,000. Importantly, the minimum length of the price bubble was determined in accordance with the proposed approach by (Phillips et al., 2015) and for the data analysed was assumed to be six months. In addition, the results are also shown for all identified bubbles, even those with a duration of one month and for bubbles that were at least twelve months long.

Table 2 Critical values for the GSADF test obtained in the Monte Carlo simulation (repetition rate = 10,000) for selected significance levels.

No.	Significance level	GSADF - determined critical value	Adopted designation
1	90	1.98	*
2	95	2.22	**
3	99	2.74	***

Source: Authors' own elaboration

Table 2 shows the critical values obtained by the Monte Carlo simulation with a repetition rate of 10,000. The test statistic value of above 2.22 will mean that at least one price bubble has been found to exist in the time series at $\alpha=0.05$. These values were obtained assuming that the minimum length of the test window, in the ADF test, was calculated according to the rule (Phillips et al., 2015):

$$r_0 = \left(0.01 + \frac{1.8}{\sqrt{T}}\right) * T$$

Where T is the total number of observations in the time series.

Table 3 shows the results for the commodities tested based on the testing assumptions described above.

Table 3 Testing of individual commodities - GSADF test values.

No.	Commodity	GSADF test value	Significance level	GSADF test conclusion
1	Banana	0.331		Cannot reject H0
2	Beef	6.793	***	Rejects H0 at 1% significance level
3	Cocoa	1.839		Cannot reject H0
4	Coconut oil	4.475	***	Rejects H0 at 1% significance level

5	Coffee	4.985	***	Rejects H0 at 1% significance level
6	Cotton	9.230	***	Rejects H0 at 1% significance level
7	Fish meal	6.861	***	Rejects H0 at 1% significance level
8	Groundnuts	3.826	***	Rejects H0 at 1% significance level
9	Logs	7.668	***	Rejects H0 at 1% significance level
10	Maize	4.235	***	Rejects H0 at 1% significance level
11	Meat, chicken	3.827	***	Rejects H0 at 1% significance level
12	Orange	1.560		Cannot reject H0
13	Palm oil	6.349	***	Rejects H0 at 1% significance level
14	Plywood	4.964	***	Rejects H0 at 1% significance level
15	Rice	11.416	***	Rejects H0 at 1% significance level
16	Sawnwood	2.849	***	Rejects H0 at 1% significance level
17	Shrimps	2.395	**	Rejects H0 at 5% significance level
18	Soybeans	4.612	***	Rejects H0 at 1% significance level
19	Sugar	4.641	***	Rejects H0 at 1% significance level
20	Tea	2.849	***	Rejects H0 at 1% significance level
21	Tobacco	3.425	***	Rejects H0 at 1% significance level
22	Wheat	4.768	***	Rejects H0 at 1% significance level
23	Coal	9.054	***	Rejects H0 at 1% significance level
24	Crude oil	5.788	***	Rejects H0 at 1% significance level
25	Natural gas	4.417	***	Rejects H0 at 1% significance level
26	Aluminium	5.751	***	Rejects H0 at 1% significance level
27	Copper	8.413	***	Rejects H0 at 1% significance level
28	Gold	6.985	***	Rejects H0 at 1% significance level
29	Iron ore	15.098	***	Rejects H0 at 1% significance level
30	Lead	9.925	***	Rejects H0 at 1% significance level
31	Nickel	9.074	***	Rejects H0 at 1% significance level
32	Platinum	5.408	***	Rejects H0 at 1% significance level
33	Silver	8.174	***	Rejects H0 at 1% significance level
34	Tin	8.246	***	Rejects H0 at 1% significance level
35	Zinc	10.682	***	Rejects H0 at 1% significance level

Source: Authors' own elaboration

Only for the three commodities tested in the agriculture & livestock sector, i.e. Bananas, Cocoa and Orange juice, there is no basis to conclude that there are price bubbles. This means that these commodities may be investments which, for potential investors, should be characterized by low investment risk and have a positive impact on the diversification of the investment portfolio, as they are not susceptible to various external shocks such as a financial crisis or a pandemic. For the commodity of Shrimps, the occurrence of at least one price bubble was identified, but at $\alpha=0.05$, while for the other commodities tested, the non-occurrence of price bubbles was rejected at $\alpha=0.01$ – the highest considered level. As a result, bubbles were found for 32 of the 35 commodities analysed during the study period, showing that the commodity market is highly exposed to temporary valuations that exceed the fundamental value.

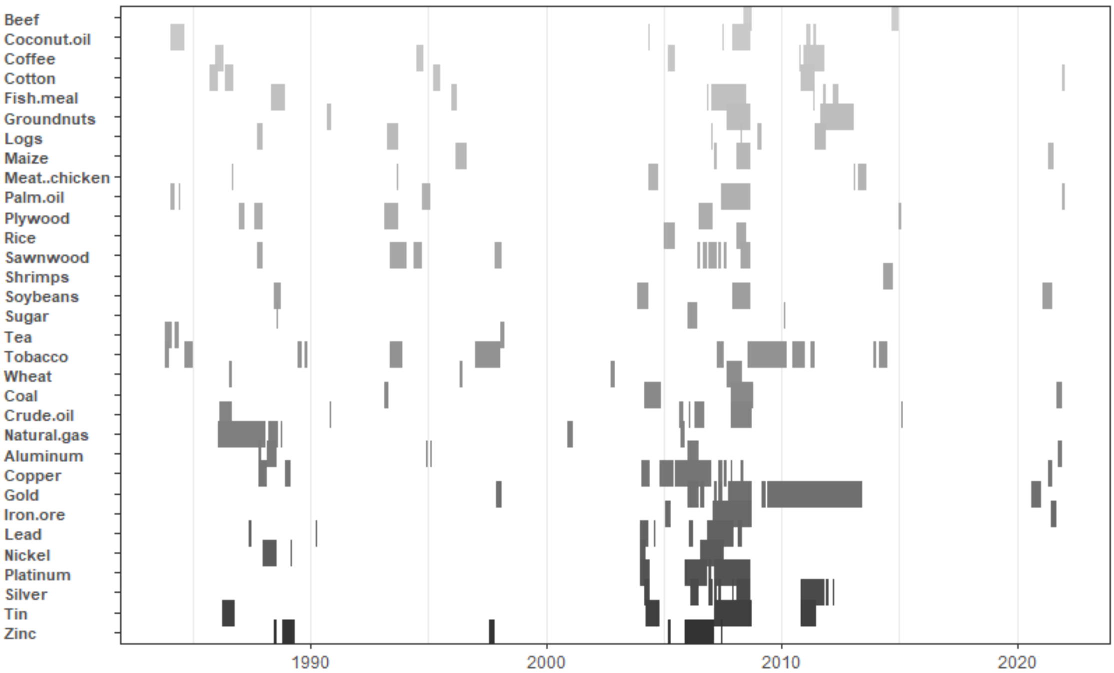
In the next step, time ranges of bubbles were defined. A total of 175 ranges were defined as bubbles. However, this total number included 126 ranges shorter than 6 months so that in the end, 49 time ranges were defined in the light of the assumption of the minimum duration of a bubble. Of which:

- five ranges of bubbles were defined for Tin,
- four ranges of bubbles were defined for Tobacco,
- three ranges for Gold.

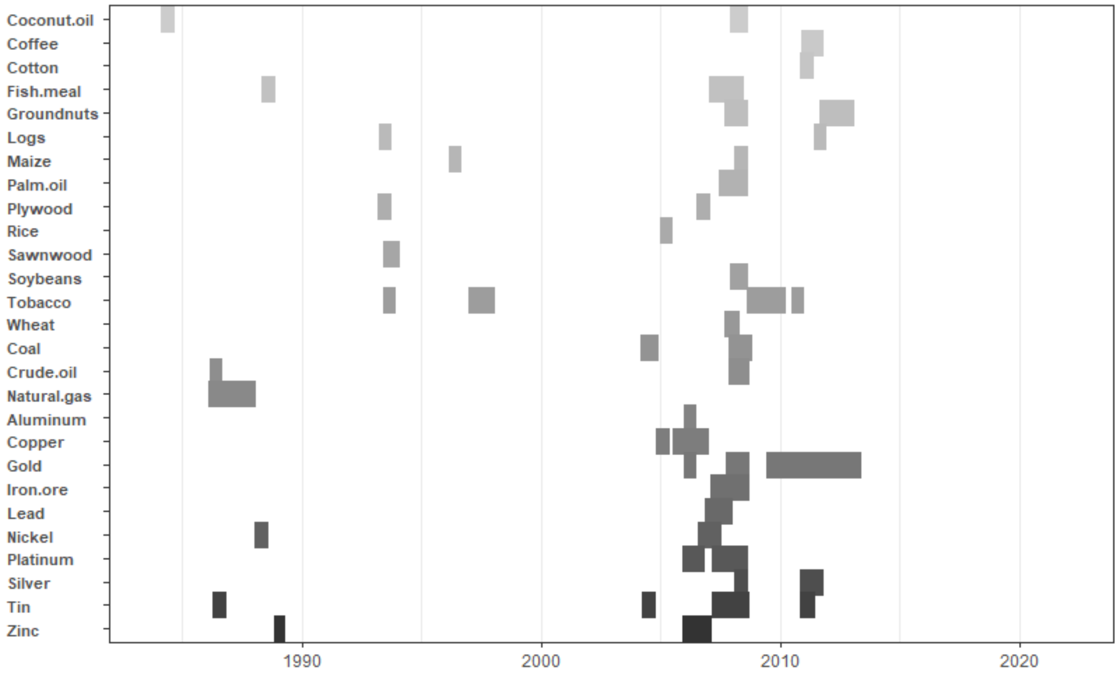
For the remaining commodities, two such ranges were identified each (13 commodities), and for the remaining 11 commodities, one such range was identified each. In addition, for five of the commodities, the time ranges of bubbles, for the longest range, were shorter than 6 months. These commodities were Beef, Meat chicken, Shrimps, Sugar, Tea. The figure below shows the time distribution for the determined time ranges of bubbles. The distribution is presented for three situations depending on the assumed minimum length of the bubble.

Figure 1 Time ranges of the bubbles depending on the minimum length of the bubble.

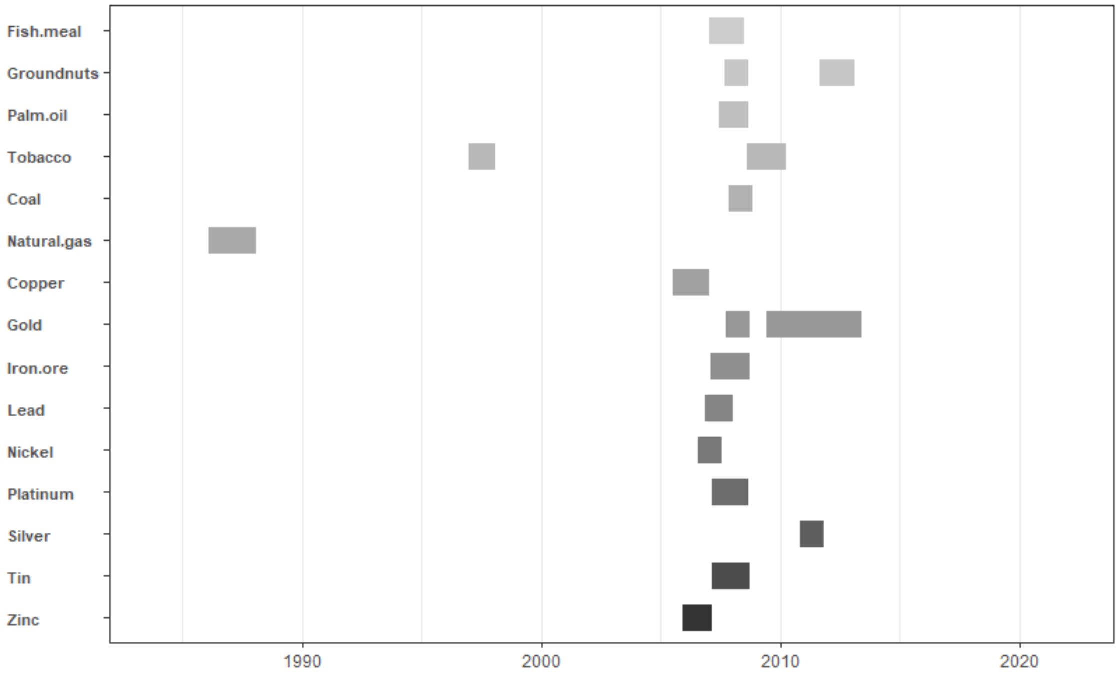
A) All time ranges identified as price bubbles.



B) Price bubbles lasting at least six months



C) Price bubbles lasting at least one year

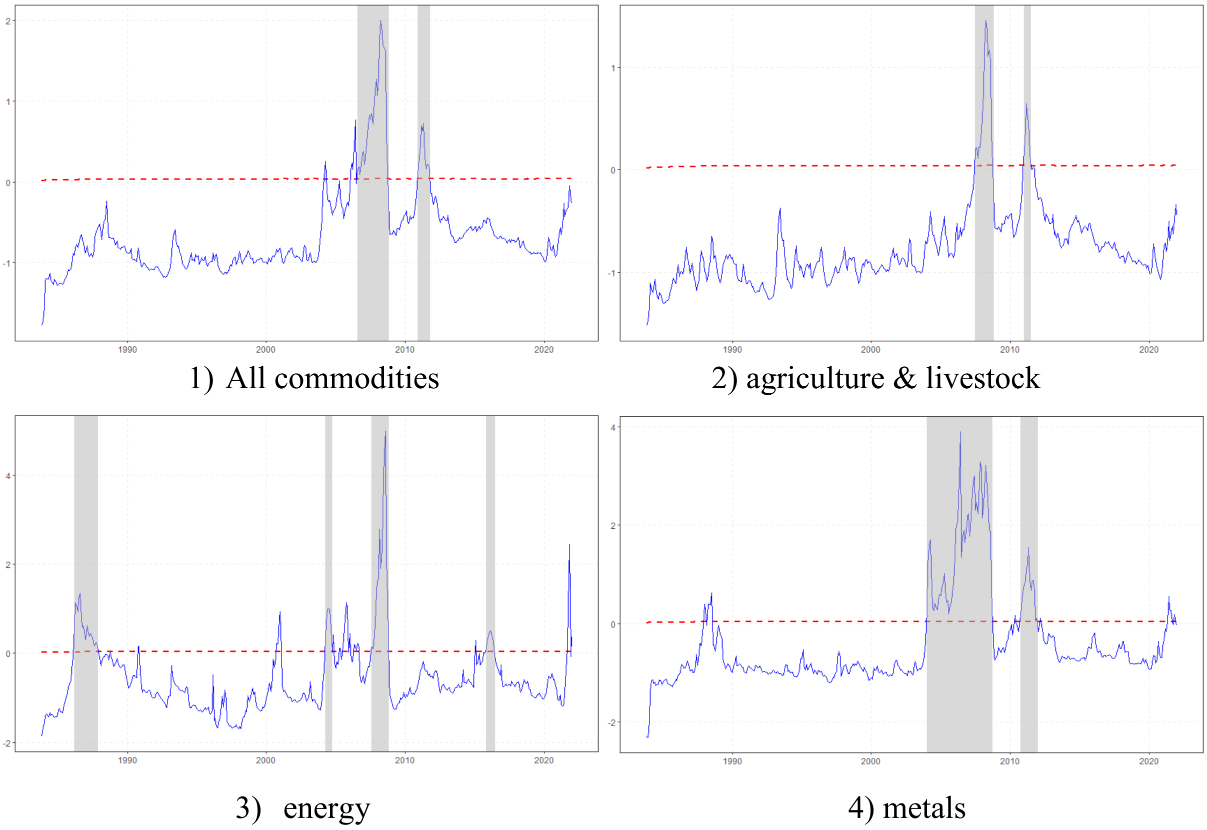


Source: Authors' own elaboration.

As presented in Figure 1, the majority of the bubbles fall within the period of 2005-2010, i.e. are related to the financial crisis of 2008. Interestingly, no bubbles periods of more than six months were identified for the commodities tested during the COVID-19 pandemic. For 49 bubbles lasting for at least 6 months, the total duration was found to be 548 months, with the longest continuous single bubble duration of 48 months for Gold, for which bubbles were found to occur for a total of 66 months, which is the longest period among all commodities tested in this study and a surprising result considering that gold is perceived as a safe heaven asset (Baur & Lucey, 2010; Baur & McDermott, 2010; Potrykus, 2015). For the commodities of Tin and Tobacco, the total length of periods marked as a bubble is 49 and 45 months respectively.

In the next step, the investigation focused on whether a bubble could be said to exist for the analysed commodities if a panel test was performed. Critical values for panel GSADF and panel BSADF tests were obtained using the sieve bootstrap method with a repetition rate of 10,000. The test was carried out for all commodities in total and by the three sectors previously identified.

Figure 2 Periods of bubbles lasting at least six months for the analysed commodity groups – panel analysis.



Source: Authors' own elaboration.

Periods defined as price bubbles were found to occur in each group at α=0.01. The values of the calculated test statistic are presented in Table 4.

Table 4 Testing of the occurrence of price bubbles for the commodity groups - panel GSADF test values.

No.	Tested group	panel GSADF test value	Significance level
1	All commodities	2.00	***
2	agriculture & livestock	1.45	***
3	energy	4.99	***
4	metals	3.90	***

Source: Authors' own elaboration.

According to data presented in Table 4 and Figure 2, four bubbles lasting at least six months were identified for the energy sector and two each for the other panels analysed. The start, end and duration for these bubbles by group are given in Table 5.

Table 5 Characteristics of price bubbles for the commodity groups

No.	Start	End	Duration	Group
1	31.07.2006	31.10.2008	27	All commodities
2	30.11.2010	31.10.2011	11	All commodities
3	30.06.2007	31.10.2008	16	agriculture & livestock
4	31.12.2010	30.06.2011	6	agriculture & livestock
5	28.02.1986	30.11.1987	21	energy
6	31.03.2004	30.09.2004	6	energy
7	31.07.2007	31.10.2008	15	energy
8	31.10.2015	30.06.2016	8	energy
9	31.12.2003	30.09.2008	57	metals
10	30.09.2010	31.12.2011	15	metals

Source: Authors' own elaboration.

Interestingly, in each of the identified panels, a price bubble period was found at the same time – during the financial crisis of 2007. For the four examined groups from 07.2007 to 08.2008, the value of the test statistics exceeds the calculated critical value of the test, which indicates that the groups of commodities identified in this way are not resistant to bubbles periods. Sharp price increases for the analysed commodities can be seen, also in these periods, which should be associated with the interest of investors in hard assets in times of crisis on financial markets. In addition, with the exception of the energy group, there was a bubble at the end of 2010 and the beginning of 2011, which is undoubtedly linked to the European debt crisis. Both these events confirm that the turbulence in financial markets is carried over into commodity markets in uncertain times, triggering price bubbles there. This study confirms the shift of interest in investing capital to commodity markets and a significant increase in prices during such periods, which is a clue for investors in the times of uncertainty, who prefer to focus on assets with real and not just financial value in such times.

5. Conclusion

The study revealed that among the commodities, there may be those in the agriculture & livestock sector that are resistant to the formation of bubbles. These included Bananas, Cocoa and Orange juice, so it can be concluded that investments in these commodities should contribute positively to adding their prices to an investment portfolio. The absence of bubbles in these markets will ensure a low correlation of returns with other investments, and this will contribute to reducing the investment risk of such a portfolio in the event of unforeseen and sudden market events. The absence of price bubbles for these commodities is also a sign that they are not attractive markets for speculators. In addition, commodities that are not very prone to bubbles, which, if do occur, are short and occur only occasionally, are Beef, Meat chicken, Shrimps, Sugar, Tea. What these two separate groups have in common is that all these investments are from the agriculture & livestock sector. Meanwhile, commodities for which the longest and most numerous periods classified as bubbles included Tin, Tobacco and Gold. The inclusion of gold in this group is surprising, as it is seen as a safe and hedge investment in the times of uncertainty in financial markets. For this commodity, a total of nine periods were identified as bubbles, but only three of them had a duration of more than six months. These were linked to the financial crisis of 2008 and the subsequent European debt crisis. This confirms the conclusions drawn in earlier studies, which also found bubbles in the gold market (Białkowski et al., 2015; Lucey & O'Connor, 2013; Pan, 2018; Wahab & Adewuyi, 2021). This fact should be explained as follows: a collapse in traditional markets causes an increased interest in the gold market, which triggers an immediate and temporary above-average price rise in that market known as a bubble. Commodities whose prices are also susceptible to the occurrence of numerous bubble periods lasting at least six months also include Plywood, Coconut oil, Soybeans, Palm oil, Nickel, Lead, Iron ore, Coal, Crude oil, Coffee, Zinc, Groundnuts, Silver, Sawnwood, Platinum, Fish meal, Natural gas and Copper. These commodities experienced bubbles lasting at least two years in total. This means that when deciding whether to buy or sell them, they require considerable knowledge from companies using them or investors as well as additional analyses. Importantly, the group of commodities most exposed to bubbles includes all energy sector commodities analysed in this paper and nine of the ten commodities from the metals sector (except for aluminium).

The fact that energy and metals sectors are more exposed to bubbles than the agriculture & livestock sector is confirmed by the panel results. In both sectors, the total duration of bubbles was longer than four years, while for the agriculture & livestock sector, it did not exceed two years. Importantly, the occurrence of bubble periods in the context of the financial crisis of 2008 was identified for each separate panel. When considering all commodities as a whole, the existence of a bubble in the period of 2010 to 2011, which results from the European debt crisis, was demonstrated as well.

As a result, this study is valuable for commodity analysts, investors, companies and policymakers. It can also be used to argue that energy and metals sectors are exposed to frequent bubbles lasting longer than 6 months, while the agriculture & livestock sector is not homogeneous in this respect and includes both commodities that are not susceptible to the occurrence of bubbles whatsoever and those that are similar to the commodities from energy and metals sectors.

6. Bibliography

Adämmer, P., & Bohl, M. T. (2015). Speculative bubbles in agricultural prices. *Quarterly Review of Economics and Finance*, *55*(May 2008), 67–76. https://doi.org/10.1016/j.qref.2014.06.003

Ajmi, A. N., Hammoudeh, S., & Mokni, K. (2021). Detection of bubbles in WTI, brent, and Dubai oil prices: A novel double recursive algorithm. *Resources Policy*, *70*(November 2020), 101956. https://doi.org/10.1016/j.resourpol.2020.101956

Balcilar, M., Ozdemir, Z. A., & Yetkiner, H. (2014). Are there really bubbles in oil prices? *Physica A: Statistical Mechanics and Its Applications*, *416*, 631–638. https://doi.org/10.1016/j.physa.2014.09.020

Basse, T., Klein, T., Vigne, S. A., & Wegener, C. (2021). U.S. stock prices and the dot.com-bubble: Can dividend policy rescue the efficient market hypothesis? *Journal of Corporate Finance*, *67*(January), 101892. https://doi.org/10.1016/j.jcorpfin.2021.101892

Baur, D. G., & Lucey, B. M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financial Review*, *45*(2), 217–229. https://doi.org/10.1111/j.1540-6288.2010.00244.x

Baur, D. G., & McDermott, T. K. (2010). Is gold a safe haven? International evidence. *Journal* *of Banking and Finance*, *34*(8), 1886–1898. https://doi.org/10.1016/j.jbankfin.2009.12.008

Białkowski, J., Bohl, M. T., Stephan, P. M., & Wisniewski, T. P. (2015). The gold price in times of crisis. *International Review of Financial Analysis*, *41*, 329–339. https://doi.org/10.1016/j.irfa.2014.07.001

Campbell, J. Y., Lo, A. W., & MacKinlay, A. C. (2012). The econometrics of financial markets. In *The Econometrics of Financial Markets*.

Caspi, I. (2017). Rtadf: Testing for bubbles with EViews. *Journal of Statistical Software*, *81*(November). https://doi.org/10.18637/jss.v081.c01

Chen, G., Chen, L., Liu, Y., & Qu, Y. (2021). Stock price bubbles, leverage and systemic risk. *International Review of Economics and Finance*, *74*(January), 405–417. https://doi.org/10.1016/j.iref.2021.03.017

Cheng, F., Wang, C., Cui, X., Wu, J., & He, F. (2021). Economic policy uncertainty exposure and stock price bubbles: Evidence from China. *International Review of Financial Analysis*, *78*(July), 1–12. https://doi.org/10.1016/j.irfa.2021.101961

Commodity Markets. (2022). “Pink Sheet” Data. https://www.worldbank.org/en/research/commodity-markets

Diba, B. T., & Grossman, H. I. (1988). The Theory of Rational Bubbles in Stock Prices. *The Economic Journal*, *98*(392), 746–754. https://doi.org/10.2307/2233912

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the Estimators for Autoregressive Time Series With a Unit Root. *Journal of the American Statistical Association*, *74*(366), 427–431. https://doi.org/10.2307/2286348

DOW JONES COMMODITY INDEX Index Attributes. (2022).

El Montasser, G., Gupta, R., Martins, A. L., & Wanke, P. (2015). Are there multiple bubbles in the ethanol-gasoline price ratio of Brazil? *Renewable and Sustainable Energy Reviews*, *52*, 19–23. https://doi.org/10.1016/j.rser.2015.07.085

Fantazzini, D. (2016). The oil price crash in 2014/15: Was there a (negative) financial bubble? *Energy Policy*, *96*(November 2014), 383–396.

https://doi.org/10.1016/j.enpol.2016.06.020

Feng, Q., & Wu, G. L. (2015). Bubble or riddle? An asset-pricing approach evaluation on China's housing market. *Economic Modelling*, *46*, 376–383. https://doi.org/10.1016/j.econmod.2015.02.004

Gilchrist, S., Himmelberg, C. P., & Huberman, G. (2005). Do stock price bubbles influence corporate investment? *Journal of Monetary Economics*, *52*(4 SPEC. ISS.), 805–827. https://doi.org/10.1016/j.jmoneco.2005.03.003

Hu, Y., & Oxley, L. (2018). Bubble contagion: Evidence from Japan's asset price bubble of the 1980-90s. *Journal of the Japanese and International Economies*, *50*(September), 89–95. https://doi.org/10.1016/j.jjie.2018.09.002

Khan, K., & Derindere Köseoğlu, S. (2020). Is palladium price in bubble? *Resources Policy*, *68*(August). https://doi.org/10.1016/j.resourpol.2020.101780

Khan, K., Su, C. W., & Khurshid, A. (2022). Do booms and busts identify bubbles in energy prices? *Resources Policy*, *76*(December 2021), 102556. https://doi.org/10.1016/j.resourpol.2022.102556

Khan, K., Su, C. W., & Rehman, A. U. (2021). Do multiple bubbles exist in coal price? *Resources Policy*, *73*(July), 102232. https://doi.org/10.1016/j.resourpol.2021.102232

Khan, K., Su, C. W., Umar, M., & Yue, X. G. (2021). Do crude oil price bubbles occur? *Resources Policy*, *71*(August 2020), 101936. https://doi.org/10.1016/j.resourpol.2020.101936

Li, Y., Chevallier, J., Wei, Y., & Li, J. (2020). Identifying price bubbles in the US, European and Asian natural gas market: Evidence from a GSADF test approach. *Energy Economics*, *87*, 104740. https://doi.org/10.1016/j.eneco.2020.104740

Lucey, B. M., & O'Connor, F. A. (2013). Do bubbles occur in the gold price? An investigation of gold lease rates and Markov Switching models. *Borsa Istanbul Review*, *13*(3), 53–63. https://doi.org/10.1016/j.bir.2013.10.008

Mao, Q., Ren, Y., & Loy, J. P. (2021). Price bubbles in agricultural commodity markets and contributing factors: evidence for corn and soybeans in China. *China Agricultural Economic Review*, *13*(1), 91–122. https://doi.org/10.1108/CAER-10-2019-0190

Narayan, P. K., Mishra, S., Sharma, S., & Liu, R. (2013). Determinants of stock price bubbles. *Economic Modelling*, *35*, 661–667. https://doi.org/10.1016/j.econmod.2013.08.010

Oladosu, G. (2022). Bubbles in US gasoline prices: Assessing the role of hurricanes and anti–price gouging laws. *Journal of Commodity Markets*, *January 2020*. https://doi.org/10.1016/j.jcomm.2021.100219

Ozgur, O., Yilanci, V., & Ozbugday, F. C. (2021). Detecting speculative bubbles in metal prices: Evidence from GSADF test and machine learning approaches. *Resources Policy*, *74*(June), 102306. https://doi.org/10.1016/j.resourpol.2021.102306

Pan, W. F. (2018). Sentiment and asset price bubble in the precious metals markets. *Finance Research Letters*, *26*(December 2017), 106–111. https://doi.org/10.1016/j.frl.2017.12.012

Phillips, P. C. B., Shi, S., & Yu, J. (2015). Testing for multiple bubbles: Historical episodes of exuberance and collapse in the S&P 500. *International Economic Review*, *56*(4), 1043–1078. https://doi.org/10.1111/iere.12132

Phillips, P. C. B., Wu, Y., & Yu, J. (2011). Explosive Behavior In The 1990S Nasdaq: When Did Exuberance Escalate Asset Values?*. *International Economic Review*, *52*(1), 201–226. https://doi.org/10.1111/j.1468-2354.2010.00625.x

Pindyck, R. S. (1993). The Present Value Model of Rational Commodity Pricing. *The Economic Journal*, *103*(418), 511–530. https://doi.org/10.2307/2234529

Potrykus, M. (2015). Investment in Gold − Safe Haven, Hedge or Source of Diversification for Polish Investor. *Nauki o Finansach = Financial Sciences*, *3*(24), 193–207. https://doi.org/10.15611/nof.2015.3.11

Sharma, S., & Escobari, D. (2018). Identifying price bubble periods in the energy sector. *Energy Economics*, *69*, 418–429. https://doi.org/10.1016/j.eneco.2017.12.007

Su, C. W., Wang, K. H., Chang, H. L., & Dumitrescu-Peculea, A. (2017). Do iron ore price bubbles occur? *Resources Policy*, *53*(August), 340–346. https://doi.org/10.1016/j.resourpol.2017.08.003

Su, C. W., Wang, X. Q., Zhu, H., Tao, R., Moldovan, N. C., & Lobonţ, O. R. (2020). Testing for multiple bubbles in the copper price: Periodically collapsing behavior. *Resources Policy*, *65*(January). https://doi.org/10.1016/j.resourpol.2020.101587

Vasilopoulos, K., Pavlidis, E., & Martínez-García, E. (2020). Exuber: Recursive Right-Tailed Unit Root Testing with R. *Federal Reserve Bank of Dallas, Globalization Institute Working Papers*, *2020*(383). https://doi.org/10.24149/gwp383r1

Vasilopoulos, K., Pavlidis, E., Spavound, S., & Martínez-García, E. (2020). *exuber: Testing and Simulating Explosive Periods*. https://cran.r-project.org/package=exuber

Wahab, B. A., & Adewuyi, A. O. (2021). Analysis of major properties of metal prices using new methods: Structural breaks, non-linearity, stationarity and bubbles. *Resources Policy*, *74*(January), 102284. https://doi.org/10.1016/j.resourpol.2021.102284

Zhang, D., Wang, T., Shi, X., & Liu, J. (2018). Is hub-based pricing a better choice than oil indexation for natural gas? Evidence from a multiple bubble test. *Energy Economics*, *76*, 495–503. https://doi.org/10.1016/j.eneco.2018.11.001

Zhang, Y. J., & Yao, T. (2016). Interpreting the movement of oil prices: Driven by fundamentals or bubbles? *Economic Modelling*, *55*, 226–240. https://doi.org/10.1016/j.econmod.2016.02.016