International Review of Financial Analysis 83 (2022) 102329

Contents lists available at ScienceDirect

International Review of Financial Analysis

journal homepage: www.elsevier.com/locate/irfa

Diamond investments – Is the market free from multiple price bubbles?

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ARTICLE INFO

Classification codes:
E3
G12

Keywords:
Multiple price bubbles
Generalised supremum ADF
Diamond market

ABSTRACT

The following study aims to investigate whether multiple price bubbles, in which the quoted market price of diamonds significantly deviates from their fundamental value, exist in the diamond market. It was conducted using ADF, SADF and GSADF tests, with the latter found to be an optimal form of evaluating the analysed issue.

The presented results support the conclusion that the diamond market is not free from periods defined as price bubbles. The study revealed price bubbles related to the leading, albeit declining in recent years, position of De Beers within the market and its activities, the financial crisis of 2008, the subsequent European debt crisis, and the crisis caused by the aggression of the Russian Federation against Ukraine in 2022. However, the identified periods of speculative bubbles in the diamond market are short and tend to affect the rough diamond segment earlier than the broader diamond market.

1. Introduction

Diamonds are one of the least recognised types of investments, referred to as alternative, or more specifically, emotional investments (Dimson & Spaenjers, 2011, 2014). An increased interest in such investments is particularly noticeable in periods of heightened volatility in capital markets. In recent years, it was triggered by various crises (Masset & Weisskopf, 2018). However, as shown in this publication, diamonds are not in the mainstream of researchers' interest compared to other types of investments. This paper aims to investigate whether this market, similarly to other previously analysed markets involving alternative investments, is susceptible to periods referred to in economic theory as speculative bubbles (Balcilar, Ozdemir, & Yetkiner, 2014; Khan, Su, & Rehman, 2021; Khan & Derindere Köseoğlu, 2020; Wahab & Adewuyi, 2021; Y. J. Zhang & Yao, 2016). The identification (or its lack) of such periods within the diamond market was also combined with a search for their possible causes.

Despite an extensive literature review, the author of this paper failed to access research on such a topic. This issue should be addressed in order to gain a better understanding of the market, which adds value to the following study. The conclusions of the research should prove to be interesting not only to potential institutional or individual investors but also to market analysts and companies involved in the broader diamond industry.

Investment in diamonds deserves the interest of researchers now that the diamond market is increasing its share in the wider investment market. Diamonds have special features that make them worthy investments, even for less affluent investors. These features include the storage of considerable value in a small mass and the associated ease of transport, the use in jewellery and, more importantly, in the industry (Borowski, 2014). The unquestionable advantage of material investments, such as diamonds, is also the characteristic trait of emotional investments – an aesthetic dividend connected with the possibility of interacting with the object of investment (Erdos & Ormos, 2012; Scorcu & Zanola, 2011). The aforementioned features influenced the decision to address speculative bubbles in the diamond market.

2. Literature review

Diamonds are examples of emotional investments or investments associated with hobbies. However, they do not receive much research attention compared to other alternative investments. This is confirmed by the data summarised in Table 1.

In terms of the investment-related phrases used in the analysis, the phrase "investing in diamonds" revealed one of the lowest numbers of papers in both the EBSCO academic search engine and Google Scholar. In EBSCO, only the phrase "investing in wine" resulted in fewer papers, while in Google Scholar, "investing in diamonds" had the lowest number of results. Moreover, the results from the EBSCO multi-search engine were limited to peer-reviewed publications only. After using quotation marks, the number of hits in the EBSCO search engine was significantly reduced in the case of all phrases, as shown in the data column entitled

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https://doi.org/10.1016/j.irfa.2022.102329
Received 11 April 2022; Received in revised form 26 July 2022; Accepted 28 July 2022
Available online 30 July 2022

Table 1
The number of studies concerning the selected investment-related phrases.

No.	Phrase	EBSCO	EBSCO with " "	Google Scholar
1	Investing in art	123,971	236	615,000
2	Investing in bonds	105,136	582	779,000
3	**Investing in diamonds**	**22,311**	13	**66,800**
4	Investing in funds	258,346	3273	2,580,000
5	Investing in hedge funds	25,408	372	253,000
6	Investing in property	58,225	1484	416,000
7	Investing in shares	312,937	597	1,040,000
8	Investing in wine	15,825	21	222,000

Source: Author's elaboration.

EBSCO with " ". With this limitation in mind, it should be noted that the phrase "investing in diamonds" is still a topic that has received very little academic attention so far.

Table 2 illustrates the results of the literature review in the context of the analysis in Section 4.

As shown in Table 2 high-quality research on diamond investments includes a study by Renneboog and Spaenjers (2012), in which the authors prove that diamond investments have higher rates of return than capital market investments. It covered the period between 1999 and 2010, at a frequency of six months. The analysed stones were divided into white diamonds, diamonds in fancy colours and other stones, such as emeralds, rubies and sapphires. It was revealed that during the study period, the average annual real rate of return on white diamonds was 6.4% while that on diamonds in fancy colours was 2.9%. From the second half of 2003 onwards, the determined rates of return were even higher – 10.0% and 5.5%, respectively. Investment in diamonds was also proven to have a higher return than investment in bonds, but a lower one compared to gold. More importantly, the authors also indicated a strong correlation between returns on diamond and capital market investments, which, as they explain, stems from the stock market wealth effect on luxury consumption.

The characteristics of diamond investments compared to precious metal investments in terms of protection against the depreciation of the US dollar were investigated in the paper by Bedoui et al. (2020). The authors emphasised that investment in gold, silver, palladium or platinum is a better hedge against USD exchange rate fluctuations than investment in diamonds or rhodium. However, both precious metals and diamonds were described as a weak safe haven with regard to USD exchange rate fluctuations. The paper analyses daily data from the period between 1 January 2002 and 19 July 2016. In terms of diamond investments, a total of six different data series were analysed according to the carat weight and purity of the stones. Similar conclusions to those made by Bedoui et al. are also presented in the study by Auer (2014), who emphasised the superiority of investment in gold and silver over diamonds. Auer described the latter as a weak hedge and safe haven against stock market downturns. A comparison of characteristics of a safe haven and a hedge for diamonds and precious metals, but during volatile periods in financial markets, was also made in the paper by Low et al. (2016). The authors of the aforementioned study proved that precious metal investments prevail over diamond investments in the analysed fields. They clearly stated that investing in precious metals protects an investment portfolio better than investing in diamonds during periods of high volatility in financial markets. Direct purchase of diamonds was also proven to yield higher returns than passive investment through indices that reflect changes for a broader market. The paper included the analysis of daily data from 4 August 2003 to 2 August 2013 relating to investments in the form of gold, silver, palladium, platinum and rhodium and a total of eight data series regarding diamond investments. The analysis of diamonds and precious metals in view of their capacity to reduce the risk revolving around an investment portfolio was conducted by Barbi et al. (2020). With regard to precious metals, the research focused on the same five investments as the previously mentioned publication. In terms of diamond investments, ten price indices, according to the carat weight (0.3, 0.5, 1.0 ct) and the use of stones (fine, commercial and mixed), were included. The listings of five companies from the diamond mining industry were also used. In contrast to the previously cited studies, this paper revealed that the capacity of diamond investments to reduce the risk of an investment portfolio is greater than that of precious metal investments. This conclusion was confirmed for diamond price indices but not for investment in diamond mining companies. The research period adopted in that publication fell between 1 June 2007 and the end of October 2018. Only the daily data were used. The lack of correlation between diamond prices, represented by price indices, and the prices of twenty-one diamond mining companies was also highlighted in research by Jotanovic and D'Ecclesia (2019), in which long-term conditional relations and a multifactor market model were analysed.

Advantages resulting from the diversification of an investment portfolio with diamond investments were also proven in a study by Auer and Schuhmacher (2013). It was conducted between 2002 and 2012 using monthly data. Diamond prices were obtained from PolishedPrices.com. Although the benefits of such diversification were confirmed, a statistically significant result was obtained for the world market portfolio with a high share of diamond investments – exceeding 50%. Investment in gold was identified to have better diversification properties in terms of improving portfolio efficiency, availability and liquidity, with positive effects observed already at 5–10%. Another study (D'Ecclesia & Jotanovic, 2018) also highlighted the characteristics of diamond investments as hedges, diversifiers or safe havens against stock market indices and bonds. In that paper, two original indices were used in relation to the diamond market, which were determined at a weekly frequency from 1 January 2002 to 25 April 2014. Advantages of the diversification of an investment portfolio with diamond investments were also proven in a study by Small et al. (2012). The authors based their conclusions on the analysis of the correlation between returns on diamond investments and selected indices representing the financial market.

A slightly different study was conducted by Potrykus (2015), who established how individual variables of the 4c diamond classification affect the valuation of these stones. The research revealed, for example, that the average difference in diamond valuation due to a one-grade difference in stone colour amounts to more than 11% in the case of diamonds under study (more than 265,000 stones were analysed). The difference in price between adjacent grades defining stone's purity is more than 8%, and for the cut quality, it is less than 5%. It was also found that on average, the highest prices include spherical stones, while other diamond shapes are 20–30% cheaper. In another publication, Potrykus (2017) analysed relationships between values of diamonds in fancy colours. Based on that study, it was found that the highest prices are recorded in the case of stones with a dominant blue colour, followed by pink and then green, yellow and brown. Compared to pink stones, blue stones are more than 570% more expensive. In contrast, stones with a dominant green, yellow or brown colour are cheaper by 62%, 69% and 89%, respectively. Potrykus also noted a significant reduction in diamond prices at the end of 2015.

The above article shares the main topic with other works. For example, interesting information about the so-called focal points of diamonds that have different valuation profiles than diamonds with different caratages is given in Scott and Yelowitz (2010). The use of neural networks and regression trees is indicated as a method for tackling difficulties associated with the valuation of diamonds (Cardoso & Chambel, 2005).

As shown in Table 2, the main focus of research dedicated to diamond investments is divided into a few topics. They include:

- analysis of the historical rate of returns on diamond investments,
- description of determinants influencing the price of diamonds,
- Assessment of safe haven, hedge or diversification properties of diamonds.

Table 2
Literature review – results.

No.	Publication	Main topic	Research gap/research questions	Summarised insights	Research period
1	(Renneboog & Spaenjers, 2012)	Evaluation of historical investment performance of diamonds and other gems.	Have diamond investments outperformed stocks RoR? Is RoR from diamond investments positively correlated with stocks?	White and coloured diamonds outperformed stocks RoR between 1999 and 2010. Gem returns covary positively with stock returns.	1999–2010/half-year
2	(Bedoui, Guesmi, Kalai, & Porcher, 2020)	Assessment of the hedging and safe haven ability of diamonds and five precious metals against the exchange rate.	Can diamonds be treated as a safe haven or a hedge against the nominal USD exchange rates? What is a better choice for investors (diamonds or precious metals) seeking to protect their investments against USD depreciation value?	Gold, silver, palladium and platinum outperform diamonds and rhodium in terms of hedging against USD movement. Precious metals and diamonds serve as a weak safe haven.	1 January 2002 to 19 July 2016/daily
3	(Auer, 2014)	Examination of the historical performance of investments in diamonds of various quality grades.	Can diamonds function as a hedge or a safe haven against stock market volatility or fluctuations of the US dollar? Can diamonds be regarded as effective diversifiers in a stock or a currency portfolio context?	The investment performance of diamonds is lower than the one of gold and silver. Diamonds have only acted as a weak hedge and a weak safe haven against stock market downturns and currency risk associated with the US dollar. Within global stock and currency portfolios, 1.0 carat fine diamonds show valuable diversification potential in that they can increase portfolio performance to an economically significant extent.	January 2002 to July 2012/weekly
4	(Low, Yao, & Faff, 2016)	Assessment of the safe haven and hedging properties of diamonds.	Can investment in diamonds have stronger safe haven and hedging properties than precious metals? What is the performance of the returns of physical diamonds compared to diamond indices?	Analysis indicates superior performance of precious metals compared to diamonds. Investors enjoy greater benefits from directly investing in physical diamonds rather than diamond indices. In the case of investors seeking to protect their assets against highly volatile market conditions, precious metals remain a better option than diamonds.	4 August 2003 to 2 August 2013/daily
5	(Barbi, Geman, & Romagnoli, 2020)	Assessments of the performance of investments in diamonds.	Are diamonds valuable in mitigating the risk of a globally or regionally diversified equity portfolio and improving its reward-to-risk ratio? Has investment in diamonds better performance than that of gold and other precious metals in terms of preserving their value over time?	Diamonds have superior diversification potential compared to gold and other precious metals. Investment in diamonds significantly improves the reward-to-risk ratio of a well-diversified equity portfolio. The same result was not achieved by gold and other precious metals tested.	1 June 2007 to the end of October 2018/daily
6	(Jotanovic & D'Ecclesia, 2019)	Study of the potential role of diamonds in the investment context.	Is investing in the diamond equity market a more feasible and liquid alternative to investing in diamonds? Is diamond equity affected by prices of polished diamonds?	The market of diamond-mining stocks does not represent a valid investment alternative to the diamond commodity. Diamond equity returns are not driven by diamond price dynamics but rather by local market stock indices.	4 June 2007 to 15 February 2019/ daily
7	(Auer & Schuhmacher, 2013)	Diamonds as a new asset that can hedge against market volatility and be a valuable portfolio component.	What is the performance of investments in diamonds of different quality grades? What are the time-varying correlations between the returns on diamonds and traditional asset classes? Can diamonds act as potential diversifiers in a world market portfolio?	In this crisis-ridden period, an investment in a diversified diamond portfolio has outperformed a diversified stock market investment. Evidence on low time-varying correlations to traditional asset classes highlights that diamonds offer some diversification potential.	January 2002 to February 2012/ monthly
8	(D'Ecclesia & Jotanovic, 2018)	Analysis of the potential role of diamonds within an investment framework, using previously unpublished data.	What is the relationship between diamonds and other key commodities, such as gold, silver, platinum and crude oil? Can the diamond market represent a hedge or safe haven for investors?	Results suggest that the diamond indices may act as hedges, diversifiers or safe havens in relation to other commodities as well as major stock or bond market indices.	1 January 2002 to 25 April 2014/ weekly
9	(Small, Smith, & Small, 2012)	Analysis of diamonds as a source of portfolio diversification.	How can diamonds enhance the risk and return profile of an investor's portfolio? How is RoR from diamonds correlated with other investments?	Investment in diamonds can produce superior risk-adjusted portfolio returns. Investment in diamonds offers diversification opportunities.	31 December 2001 to 26 December 2011/weekly
10	(Potrykus, 2015)	Description of the main determinants influencing the success of investment in diamonds.	How do the caratage, clarity, cut, colour, shape and certification institution influence the price of a diamond?	The heavier stone the greater differences in price because of the variants of studied traits. The average difference in the valuation of diamonds due to a single difference in the colour of the stone is over 11% for all examined observations. In the case of the clarity, the average difference in price between neighbouring steps of the stone's clarity is almost 8%, and for the quality of cutting - less than 5%.	Data collected between 14 April 2014 and 17 April 2014

(*continued on next page*)

Table 2 (*continued*)

No.	Publication	Main topic	Research gap/research questions	Summarised insights	Research period
				The most expensive stones are certified by GIA, AGS and HRD, and for the ten analysed shapes, the most expensive form is round.	
11	(Potrykus, 2017)	Description of the main determinants influencing the success of investment in fancy-coloured diamonds.	How did prices of fancy coloured diamonds change in 2015? How do colour, tone and saturation affect the valuation of diamonds in fancy colours? How did prices of fancy coloured diamonds change in 2015?	The highest prices involve gems of the dominant colour blue or pink and then green, yellow and brown. The highest prices are reached by fancy vivid or fancy dark stones. The average prices of the examined stones decreased by nearly 22% in 2015.	January 2015 and December 2015/ yearly
12	(Scott & Yelowitz, 2010)	Description of determinants influencing the price of diamonds.	Are diamond prices based on focal points, which entail different valuation than in the case of stones with different caratage?	Diamond prices include sharp differences at half- and whole-carat sizes, which are not explainable by other characteristics of the diamond. For diamonds in the one-carat range, for example, owning a diamond that is one carat rather than 0.99 carats carries a 5%–10% price premium	Data collected between 6 July 2005 and 8 July 2005
13	(Cardoso & Chambel, 2005)	Description of determinants influencing the price of diamonds.	Preparation of a tool to value diamonds with different numbers and types of properties.	Neural networks have a better performance in prediction, accounting for around 96% of cut diamond unit price variation. The role of regression trees is fundamental in interpretability, helping to understand the contribution of predictors in pricing.	Data collected in October 2001

Source: Author's elaboration.

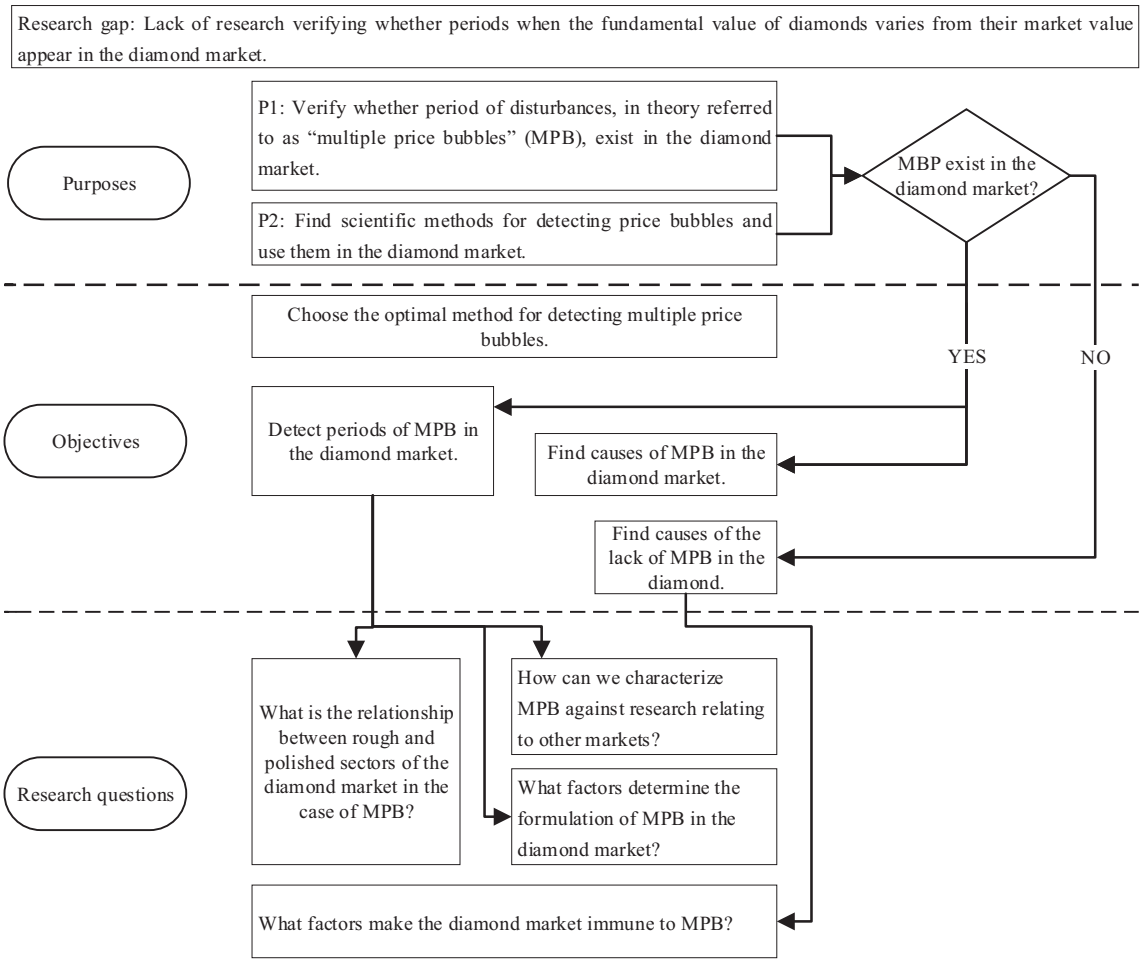

Fig. 1. The essence of the proposed research framework.
Source: Author's elaboration.

Although the literature review failed to indicate research concerning the formation of speculative bubbles in the diamond market, this study aims to fill this research gap. Such a topic is important from the scientific and practical points of view. The formulation of asset price bubbles is always a signal of asset misallocation and can have serious effects on the real economy (Phillips, Wu, & Yu, 2011). Assets bubbles in a given market are linked to negative welfare effects concerning many groups involved in this market (Su et al., 2020). Thus, the establishment of factors causing bubble periods in the diamond market, or the identification of characteristics of the market that make it resistant to such periods, will help to better understand the nature of the bubble mechanism and the process of their formulation (scientific area). From a practical point of view, the presented study is important for participants of this market, e.g. companies trading in diamonds, and the jewellery industry, but also, and perhaps above all, for investors and analysts who seek diversification benefits with the use of diamond investments.

The following sections of the article describe the data, methodology (Section 3) and research framework used in the study. Section 4 contains the results of the analysis, while Section 5 outlines the conclusions.

3. Data and methodology

As it was proven in the literature review section, the key question is: do periods when the fundamental value of diamonds varies from their market value appear in the diamond market? In theory, such time of disturbance is referred to as a price bubble. If such periods occur more often in the same market, then they are identified as multiple price bubbles (MPB). The literature review section allowed determining the research gap, which was subsequently presented in Fig. 1 along with the research framework, objectives and questions addressed in the article.

Fig. 1 presents the main objective of the paper, that is, the selection of an optimal method for detecting multiple price bubbles. In the next step, the diamond market will be tested for MBP. Subsequently, the causes for the absence or presence will be indicated. These objectives lead to specific research questions, which are also described in Fig. 1. The answers, based on the results from Section 4, are provided in the conclusion.

To find the answers to the presented research questions, four data series were analysed – two data series at a monthly frequency, in which the last observation from a given month was used, and two data series based on De Beers' sight system (DBSS) to extend the scope of the study.

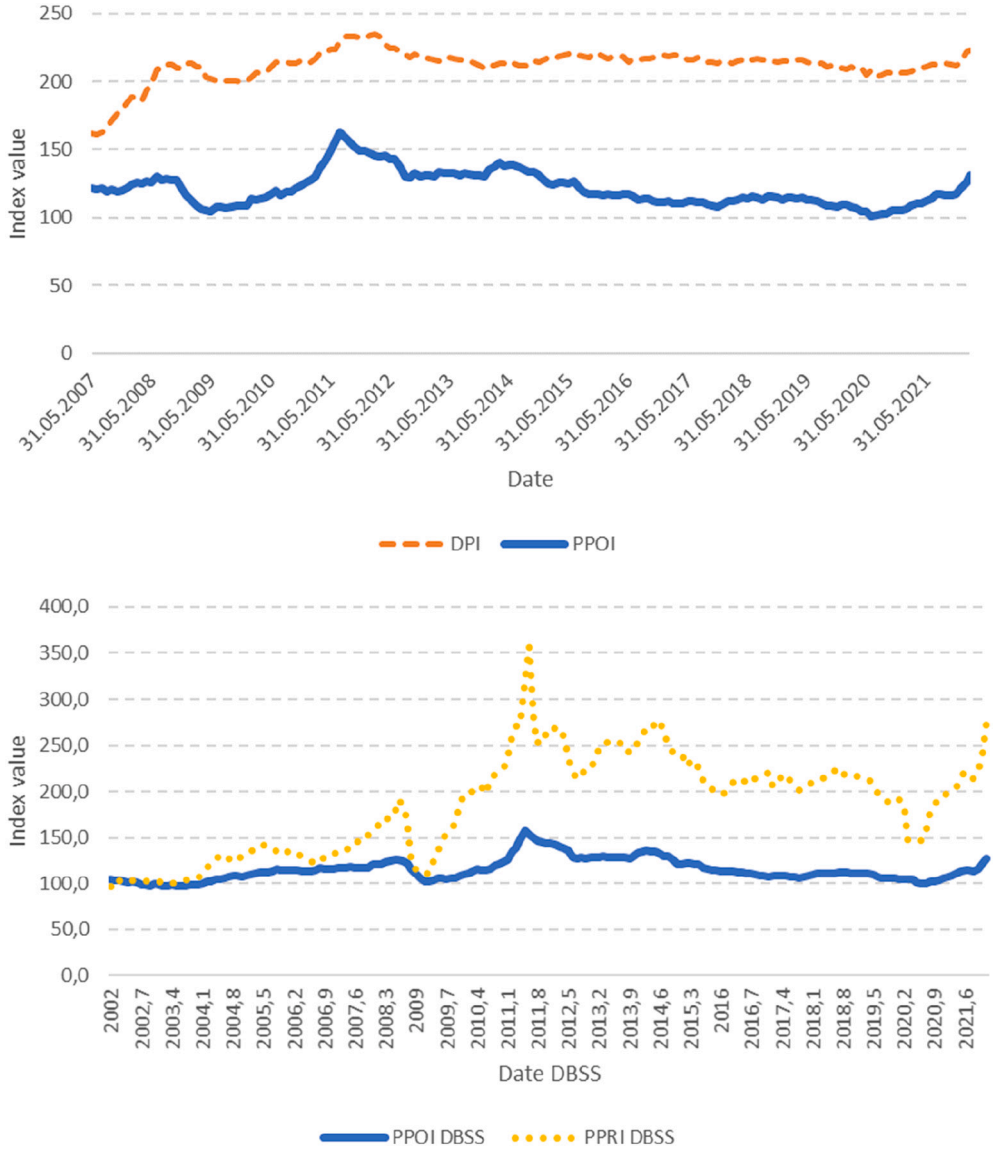

Fig. 2. Trend of diamonds prices.
Source: Author's elaboration.

De Beers controlled most of the world's supply, which is why the industry applies these cycles. The monthly frequency data cover the period from May 2007 to February 2022 and are represented by two indices – the Polished Prices Overall Index (PPOI) and the Diamond Prices Index (DPI). On the other hand, DBSS-based data cover a longer period – from 2002 until the second measurement in 2022 – and there are ten measurement points for each calendar year (lasting an average of five weeks each). With regard to data listed according to the DBSS standard, the Polished Prices Rough Index (PPRI DBSS) and the Polished Prices Overall Index (PPOI DBSS) were analysed using a base value of 100, with the first observation occurring in 2003. The values of the studied indices and their changes over time are shown in Fig. 2.

As shown in Fig. 2, the DPI, PPOI and PPOI DBSS data series assume very similar values during the period under study. In contrast, PPRI DBSS is much more volatile than other indices. The basic descriptive statistics relating to the applied indices are presented in Table 3 in order to illustrate their characteristics.

It is worth noting that the most volatile index is PPRI DBSS, with the highest standard deviation equal to 54.01 index points. The standard deviation for PPRI DBSS is more than four times bigger than in the case of other analysed indices. The coefficient of variance was also calculated to better compare the mean value of the indices and their standard deviations. Based on that result, the differences between PPRI DBSS and other indices appear to be even bigger. This is a signal that PPRI DBSS should be treated as the riskiest index from the analysed group. PPRI DBSS has also a negative kurtosis of −0.76, which is opposite to the rest of the indices and far from the kurtosis value of 6.15 established for DPI. The latter has also the smallest skewness value, amounting to −2.00. The maximum values for PPOI, PPOI DBSS and PPRI DBSS were reached in the middle of 2011. In the case of DPI, this moment was slightly moved, and the highest value was noted in February 2012. The minimum value was recorded in June 2007 for DPI, June 2020 for PPOI, on the seventh measurement point in 2003 for PPOI DBSS and the first measurement point in 2002 for PPRI DBSS.

Three statistical tests – Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1979), Supremum Augmented Dickey-Fuller (SADF) (Phillips et al., 2011) and Generalised Supremum Augmented Dickey-Fuller (GSADF) (Phillips, Shi, & Yu, 2015) – used to detect price bubbles in the studied market are shown in Fig. 1. At this point, it should be noted that the methodology of the latest GSADF test results from the evolution and changes made in the previously mentioned tests. The GSADF test is characterised not only by the moving ending window but also by different values for determining the starting point of the test. This makes it the optimal tool for testing whether price bubbles occur in the market. The formulae used in these tests are as follows (Khan et al., 2021):

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2}$$

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

where:

r_0 – minimum length of the test window,

r_1 – start of the test window,

r_2 – end of the test window,

ADF – statistic value for a "standard" ADF test described, for example, by Vasilopoulos, Pavlidis, and Martínez-García (2020).

It is necessary to determine the above values by means of the BSADF test to date-stamp the identified bubbles using the GSADF test, which, due to its characteristics, was selected as a definitive method of assessing whether and when price bubbles occurred in a market (Sharma & Escobari, 2018).

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

The research was conducted based on the aforementioned tests, whose values were calculated using the exuber v. 0.4.2 package (Vasilopoulos, Pavlidis, Spavound, & Martínez-García, 2020). The research results are described in the subsequent section.

4. Research results

The research revealed the presence of speculative bubbles in the data series under study. The results of the conducted tests are shown in Table 4.

Due to the different lengths of the data series, critical values were determined twice – for a series with 178 observations (data obtained on a monthly basis) and for a series with 202 observations (DBSS). Critical values were established by means of the Monte Carlo simulation, with a repetition rate of 10,000. In each case, the minimum length of the test window for the ADF test resulted from the following equation (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.

The research serves as the basis of the conclusion that the diamond market is exposed to price bubbles. For each series in question, the existence of price bubbles was confirmed using the GSADF test at a significance level of at least $\alpha = 0.05$. Such value was observed for the DPI series. In the case of other series under study, it was even higher – $\alpha = 0.01$. The SADF test also showed an identical significance level for the three analysed data series. However, the SADF test revealed no bubbles for the DPI series while the ADF test did not identify bubbles. The reason why such a situation took place may be associated with the fact that the GSADF test does not lose its power when the analysed time series is long and there is more than one speculative bubble, which cannot be said for

Table 3
Descriptive statistics relating to applied indices.

Descriptive statistics	*DPI*	*PPOI*	*PPOI DBSS*	*PPRI DBSS*
Mean	212.09	121.32	115.20	185.71
Median	213.95	117.45	112.95	198.25
Std.dev	12.01	12.67	12.28	54.01
Coefficient of variance [%]	5.66	10.45	10.66	29.08
Kurtosis	6.15	0.38	0.84	−0.76
Skewness	−2.00	0.89	0.97	0.06
Min	161.40	101.20	96.60	96.80
Max	234.80	163.20	158.30	357.20

Source: Author's elaboration.

Table 4
Values of test statistics along with critical values.

No.	Critical value (cv)/ calculated test statistics (cts)	Significance level/time series name	ADF	SADF	GSADF	Length of analysed time series
1	cv	90	−0.400	1.081	1.786	$T = 178$
2	cv	95	−0.022	1.376	2.064	
3	cv	99	0.673	1.901	2.613	
4	cts	DPI	−4.91	−1.80	2.09 (**)	
5	cts	PPOI	−1.09	3.30 (***)	5.70 (***)	
6	cv	90	−0.416	1.071	1.803	$T = 202$
7	cv	95	−0.043	1.377	2.082	
8	cv	99	0.656	1.970	2.624	
9	cts	PPOI DBSS	−1.17	4.06 (***)	4.23 (***)	
10	cts	PPRI DBSS	−1.43	4.17 (***)	4.28 (***)	

Source: Author's elaboration.

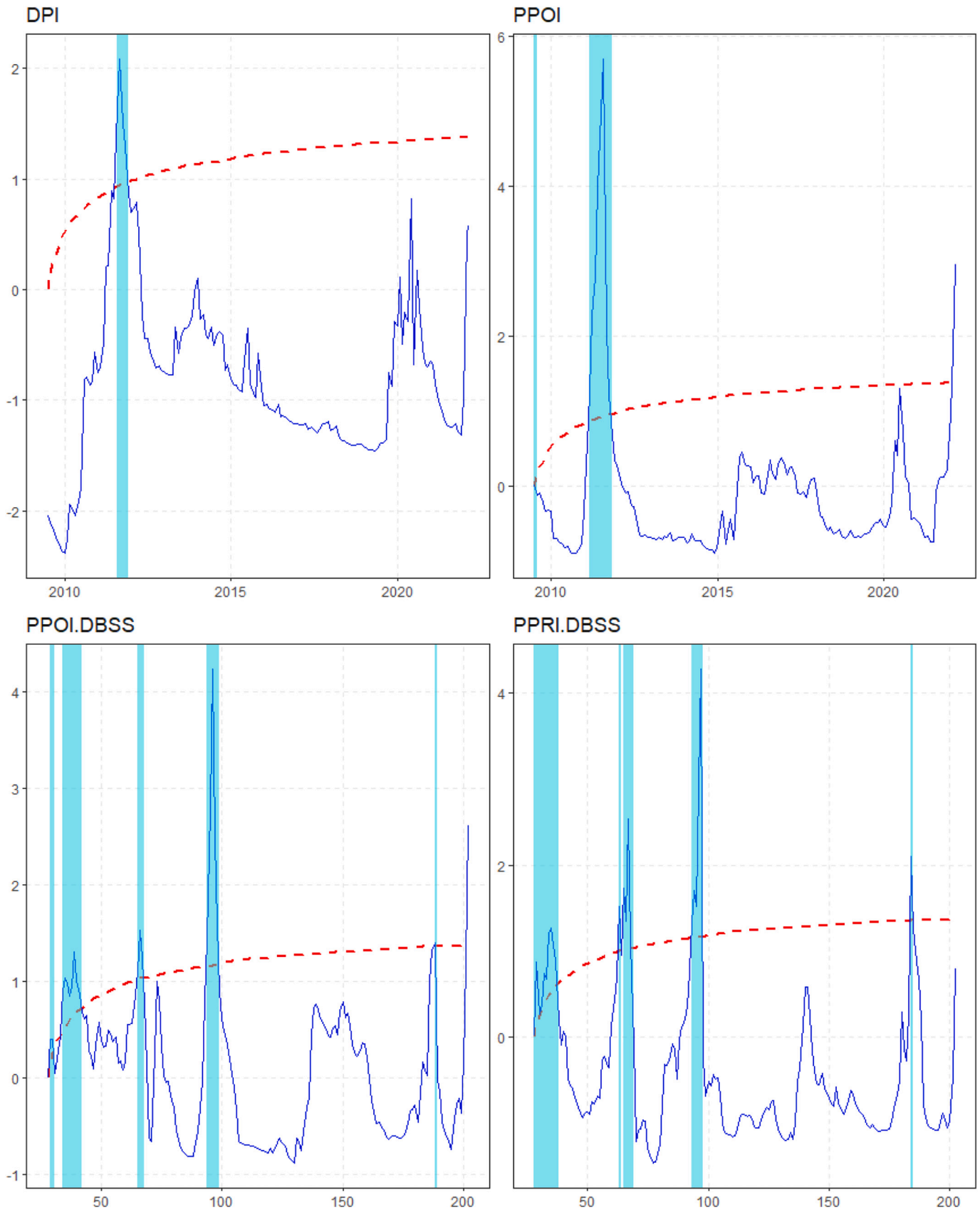

Fig. 3. Visualisation of identified periods of speculative bubbles in the analysed data series – results of the GSADF test.
Source: Author's elaboration.

Table 5
Information on the identified price bubbles – results of the GSADF test.

Time series name	Number of identified price bubbles	Starting point	Ending point	Duration (m for monthly, DBSS for De Beers' sight system)
DPI	1	29 Jul. 2011	30 Nov. 2011	4 m
PPOI	1	30 Jun. 2009	31 Jul. 2009	1 m
	2	28 Feb. 2011	31 Oct. 2011	8 m
	3	31 Jan. 2022		in progress
PPOI	1	2004, 9	2005, 1	2 DBSS
DBSS	2	2005, 4	2006, 2	8 DBSS
	3	2008, 5	2008, 8	3 DBSS
	4	2011, 4	2011, 9	5 DBSS
	5	2020, 8	2020, 9	1 DBSS
	6	2022, 2		in progress
PPRI	1	2004, 8	2005, 8	10 DBSS
DBSS	2	2008, 3	2008, 4	1 DBSS
	3	2008, 5	2008, 9	4 DBSS
	4	2011, 3	2011, 8	5 DBSS
	5	2020, 4	2020, 5	1 DBSS

Source: Author's elaboration.

the ADF and SADF tests (Khan et al., 2021). In view of the above, it is possible to conclude that periods defined as price bubbles do occur in the diamond market. A detailed analysis of price bubbles in terms of their duration and length is shown in Fig. 3 and Table 5.

As shown in Fig. 3 and Table 5, the largest number of periods defined as price bubbles (six) was detected for PPOI DBSS, five periods were identified for PPRI DBSS, three for PPOI series and one for DPI. However, it should be noted that the data series based on the DBSS standard represent a research period that is five years longer than that of the DPI and PPOI indices. Moreover, within the time common for both selected research periods – May 2007 to February 2022 – similarities were found regarding the duration and length of the identified speculative bubbles in the case of analysed indices that obtained the highest significance level. This finding supports the conclusions of the analysis.

The data series under study revealed the existence of a price bubble from the end of 2004 to the beginning of 2006 (bubbles 1 and 2 for DBSS PPOI). The next diamond price bubble took place in the second half of 2008, then the middle of 2011, while the last one has started in February 2022.

The main causes triggering the formulation of speculative bubble periods are outlined below.

The price bubble lasting from the end of 2004 to the end of 2005/beginning of 2006 resulted from the change in the distribution system of De Beers, which is the largest diamond trader in the world. It should be mentioned that De Beers' position, although weakening over time, is still crucial in this market, and the change introduced by this company caused the longest price increase period observed in this study.

The price bubble from the second half of 2008 arose in connection with the financial crisis of 2008 and the diversion of investors from financial assets to hard assets, as can be seen from the rising diamond prices during that period.

The 2011 price bubble and the increase in diamond prices that took place in that period resulted from the European debt crisis caused by the excessive debt of Greece. Interestingly, although both of these crises (in 2008 and 2011) contributed to the rise in diamond prices, the total duration of the resulting speculative bubbles is still shorter compared to the price bubble period linked to the De Beers' change in distribution. This proves the undoubtedly significant role of this company in the diamond market and the need to analyse in detail all messages issued by this entity when making decisions related to diamond investments.

According to this publication, the ongoing price bubble period, which began in February 2022, arose due to the Russian aggression against Ukraine and yet another shift of investors towards hard assets. The identification of this price bubble proves the usefulness of the GSADF test, which can be used to monitor the formation of price bubbles in real time. The end of Russia's invasion of Ukraine is likely to prevent this price bubble from maintaining its existence in the diamond market.

5. Conclusions

This publication provides the basis for concluding that periods defined as speculative bubbles, according to economic theory, do occur in the diamond market. The Generalised Supremum Augmented Dickey-Fuller test confirmed that the diamond market is not immune and does not have any special properties that protect it from multiple price bubble periods. The research section identified the reasons behind the existence of all periods under study. It can be said that in the case of the diamond market, as for other previously analysed alternative investments (Balcilar et al., 2014; Khan et al., 2021; Li, Chevallier, Wei, & Li, 2020; Su, Wang, Chang, & Dumitrescu-Peculea, 2017; Su et al., 2020; D. Zhang, Wang, Shi, & Liu, 2018), price bubbles occurred in relation to the financial crisis of 2008, the European debt crisis and the 2022 Russian invasion of Ukraine. In terms of these three price bubbles and their causes, investment in diamonds is similar to all other markets studied to date. This confirms the low impact of diamonds on portfolio diversification in times of turmoil in financial markets compared to other alternative investments, such as precious metals (Low et al., 2016). The diamond market is not resistant to external shocks, which cause differences between the fundamental value and the market value.

One of the identified price bubbles from the end of 2004 was also caused by an internal factor associated with the change in the distribution system of the largest diamond trader in the world – De Beers. It was the longest speculative bubble period in the diamond market determined in this study, which lasted a year and was linked to the high concentration of world diamond mining by the De Beers cartel. Still, this period is short as far as the other studies cited in the paper are concerned. At this point, it is necessary to point out that there is a decline in the company's share of total diamond output (Jotanovic & D'Ecclesia, 2019). This means that this market can no longer be seen as a monopoly, which will probably only increase its attractiveness to investors. Due to the decreasing role of De Beers and the fact that the diamond market is evolving into a more competitive form, the internal causes of diamond bubbles become weaker.

Nevertheless, the periods of speculative bubbles identified in the diamond market are short, which is an advantage of this type of investment and the cause of its superiority over the alternative ones, for which research results were previously cited. The short duration of price bubbles in the diamond market is a factor that may be used by investors if they wish to avoid long-term risk associated with a high variance of portfolio returns. Investment in diamonds constitutes a good offer for an investor who wants to avoid risk, but it will not save them from disturbances occurring within a short period.

Finally, the analysis also revealed that periods of speculative bubbles in the rough diamond market usually start earlier than in the broader market, which can be taken as a warning sign of bubble formation for potential investors or market analysts involved in the polished segment. This finding confirms that rough diamond prices may be regarded as an explanatory variable in predicting diamond prices in the polished part of the analysed market. This is very useful information for investors and market analysts but also for various stakeholders. The association of the emergence of short-time price bubbles in a diamond market with the fact that the rough diamond market is the first place when bubbles occur is valuable when formulating stock policy. Even when a sharp rise in prices within the diamond market is observed, this is not a signal for increasing stocks of stones since that extremely high level of prices will be temporary.

The identification of periods defined as speculative bubbles in the diamond market, along with their causes and characteristics, is the first

step of research that be extended in the future to cover analyses of the co-occurrence of price bubbles in other markets – not only in alternative investment markets but also in capital ones.

Funding

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

Declaration of Competing Interest

None.

References

Auer, B. R. (2014). Could diamonds become an investor's best friend? *Review of Managerial Science, 8*(3), 351–383. https://doi.org/10.1007/s11846-013-0108-2

Auer, B. R., & Schuhmacher, F. (2013). Diamonds - a precious new asset? *International Review of Financial Analysis, 28*, 182–189. https://doi.org/10.1016/j.irfa.2013.03.008

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

Barbi, M., Geman, H., & Romagnoli, S. (2020). Diamonds and precious metals for reduction of portfolio tail risk. *Applied Economics, 52*(26), 2841–2861. https://doi.org/10.1080/00036846.2019.1696938

Bedoui, R., Guesmi, K., Kalai, S., & Porcher, T. (2020). Diamonds versus precious metals: What gleams most against USD exchange rates? *Finance Research Letters, 34*(May 2019), 101253. https://doi.org/10.1016/j.frl.2019.08.001

Borowski, K. (2014). Analiza Uwarunkowań Inwestycyjnych Na Rynku Diamentów. *Modern Management Review*. https://doi.org/10.7862/rz.2014.mmr.44

Cardoso, M., & Chambel, L. (2005). A valuation model for cut diamonds. *International Transactions in Operational Research, 12*, 417–436.

D'Ecclesia, R. L., & Jotanovic, V. (2018). Are diamonds a safe haven? *Review of Managerial Science, 12*(4), 937–968. https://doi.org/10.1007/s11846-017-0234-3

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

Dimson, E., & Spaenjers, C. (2011). Ex post: The investment performance of collectible stamps. *Journal of Financial Economics, 100*(2), 443–458. https://doi.org/10.1016/j.jfineco.2010.12.005

Dimson, E., & Spaenjers, C. (2014). Investing in emotional assets. *Financial Analysts Journal, 70*(2), 20–25. https://doi.org/10.2469/faj.v70.n2.8

Erdos, P., & Ormos, M. (2012). Pricing of collectibles: Baedeker guidebooks. *Economic Modelling, 29*(5), 1968–1978. https://doi.org/10.1016/j.econmod.2012.06.010

Jotanovic, V., & D'Ecclesia, R. L. (2019). Do diamond stocks shine brighter than diamonds? *Journal of Risk and Financial Management, 12*(2), 79. https://doi.org/10.3390/jrfm12020079

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

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*, Article 104740. https://doi.org/10.1016/j.eneco.2020.104740

Low, R. K. Y., Yao, Y., & Faff, R. (2016). Diamonds vs. precious metals: What shines brightest in your investment portfolio? *International Review of Financial Analysis, 43*, 1–14. https://doi.org/10.1016/j.irfa.2015.11.002

Masset, P., & Weisskopf, J. P. (2018). Raise your glass: Wine investment and the financial crisis. *World Scientific Handbook in Financial Economics Series, 6*(November), 271–295. https://doi.org/10.1142/9789813232747_0012

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

Potrykus, M. (2015). Diamenty jako przykład inwestycji alternatywnej. *Financial Sciences, 2*(2). https://doi.org/10.15611/nof.2015.2.06

Potrykus, M. (2017). Diamenty w kolorach fantazyjnych–charakterystyka walorów inwestycyjnych. In *Finanse Publiczne, Rynek Finansowy, Finanse przedsiębiorstw* (pp. 147–162). Uniwersytet Łódzki.

Renneboog, L., & Spaenjers, C. (2012). Hard assets: The returns on rare diamonds and gems. *Finance Research Letters, 9*(4), 220–230. https://doi.org/10.1016/j.frl.2012.07.003

Scorcu, A. E., & Zanola, R. (2011). The "right" price for art collectibles: A quantile hedonic regression investigation of Picasso paintings. *The Journal of Alternative Investments*. https://doi.org/10.3905/jai.2011.2011.1.012, 110819050219003.

Scott, F., & Yelowitz, A. (2010). Pricing anomalies in the market for diamonds: Evidence of conformist behavior. *Economic Inquiry, 48*(2), 353–368. https://doi.org/10.1111/j.1465-7295.2009.00237.x

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

Small, K., Smith, J., & Small, E. (2012). An examination of diamonds as an alternative asset class: Do they have what it takes to make a portfolio sparkle? *Journal of Wealth Management, 15*(3), 67–74. https://doi.org/10.3905/jwm.2012.15.3.067

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), Article 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