

## **Investing in wine, precious metals and G-7 stock markets – a co-occurrence analysis for price bubbles**

### **Abstract:**

This paper used the GSADF test to determine the periods defined in this paper as price bubbles in the three markets studied, i.e. the investment wine market, precious metal market and national stock market indices of G-7 countries. The results obtained enabled the calculation of the values of the phi correlation coefficients, which served the research objective of assessing the co-occurrence of price bubbles in the markets analysed. The research period adopted in the study was December 2003 to March 2022, and the data were examined at a monthly frequency.

Based on the results, it was concluded that the periods of price bubbles in the investment wine market, relative to the other investments studied, are long and amount to a maximum of 50% of the time studied. Price bubble periods for investments in the DAX index and the Rhone 100 index or the Rest of the World 60 index will lower the risk of an investment portfolio in times of greatest turbulence in these markets. In addition, the co-occurrence of price bubbles was not confirmed for the S&P500 index and the Bordeaux Legends 40 investment. Moreover, no co-occurrence of price bubbles was identified between investments in most of the wine indices studied and investments in silver and gold. However, the same phenomenon was not confirmed for platinum investments.

### **Keywords:**

price bubbles, GSADF, investing in wine, precious metals, G-7 capital markets

### **1. Introduction**

Investments in the wine market are becoming increasingly popular among both individual and institutional investors (Le Fur et al., 2014). With the development of the London Liv-ex exchange or the expansion of auction houses' offers of various types of liquor, access to such investments is easy and attainable for numerous investors (Czupryna & Oleksy, 2018). Hence the growing number of academic studies devoted to investing in this market, e.g. (Potrykus, 2015a), or the impact of these investments on investment portfolio characteristics such as risk or rate of return (Masset & Henderson, 2018; Masset & Weisskopf, 2018; Potrykus, 2015b).

Despite the growing number of scientific studies devoted to the issue of investing in the wine market, or the broader issue of investing in emotional assets, there is a need to investigate whether the wine investment market is susceptible to the occurrence of periods that are referred to in the literature as price bubbles. This is because, as has been shown in previous studies, the occurrence of a price bubble in any market leads mainly to negative phenomena, from smaller ones such as negative welfare effect (Su et al., 2020) to larger ones such as a systemic financial crisis (Brunnermeier et al., 2020). And although it should be assumed that the formation and bursting of price bubbles in the investment wine market should not lead to the serious macroeconomic consequences mentioned by Brunnermeier et al., (2020) it is still a noteworthy problem due to the negative welfare effect. It is also important to address how the potential occurrence of price bubbles will be related to the occurrence of the same periods in equity markets or other alternative investments selected. This is a problem related to the issue of investment portfolio diversification in times of extreme turbulence in the broader investment markets. Therefore, the determination of whether there are periods of price bubbles in the investment wine market, in the same periods as in the major equity markets, will demonstrate the relevance of investing in wines in reducing investment risk, according to the Modern Portfolio Theory (Markowitz, 1952).

It is necessary to answer whether wine investments can act mainly as a hedge, not as a safe haven, based on the fact that periods defined as price bubbles in capital markets and wine markets occur at the same moment. The ability of wine investments to serve as an effective hedge against capital market movements, in general, is proven in (Bouri, 2015). Bouri also agrees that wine investment cannot serve as a safe haven, thus, through wine investment, an investor cannot reduce risk during extreme market shocks. The last cited author also agrees that his conclusions are aligned with the work of (Bouri, 2014; Sanning et al., 2008). The ability of wine investment to serve as a hedge, and the lack of safe haven properties are also given in (Jurevičienė & Jakavonytė, 2015; Łęt & Siemaszkiewicz, 2020).

Such a relation between wine prices and stock market returns, which is a base for the research questions formulated in this paper, has its theoretical background in the fact that stock market returns are correlated with wine demand and wine prices (Eyler & Sims, 1999). It was stated in previous studies (Dimson et al., 2015) that high rates of return in stock markets create a wealth effect and increase wine investment demand and wine prices, and even investments in the wine industry sector (Overton & Banks, 2015). Such a mechanism of how the wealth effect from equities impacts the wine market is presented, for example, in (Jiao, 2017). It can be assumed



then that price bubbles on stock markets can be a source of price bubbles in the wine investment market. The analysis prepared below should answer whether such an assumption is true.

In the subsequent sections of this study, a literature survey was conducted and research questions resulting from the research gap adopted were posed. In the next step, the data used for the study were characterised and the methodology used to test the occurrence of price bubbles, along with assessing their co-occurrence between the markets analysed, was described. Section four describes the results of the study. In section five, the results obtained were discussed and summarised.

## 2. Literature review

The issue of detecting price bubbles is widely covered in scientific studies. However, most of the scientific publications in this field in recent years refer mainly to raw materials (Potrykus, 2023), including in particular oil (Ajmi et al., 2021; Balcilar et al., 2014; Fantazzini, 2016; Khan et al., 2022; Khan, Su, Umar, et al., 2021; Oladosu, 2022; Sharma & Escobari, 2018; D. Zhang et al., 2018; Y. J. Zhang & Yao, 2016), natural gas (Khan et al., 2022; Li et al., 2020; Sharma & Escobari, 2018; D. Zhang et al., 2018) or gold (Białkowski et al., 2015; Lucey & O'Connor, 2013; Ozgur et al., 2021; Pan, 2018). Few works have been devoted to studying the occurrence of price bubbles in the markets for corn and soybeans (Adämmer & Bohl, 2015; Mao et al., 2021), iron ore (Su et al., 2017), copper (Su et al., 2020) or diamonds (Potrykus, 2022). With few exceptions (Adämmer & Bohl, 2015; Balcilar et al., 2014; Białkowski et al., 2015; Lucey & O'Connor, 2013; Y. J. Zhang & Yao, 2016), the GSADF test is the main research method practically in each of the referenced studies.

Such a dominant position of the GSADF test as a research method has not been observed in studies on capital markets that address the issue of the occurrence of price bubbles in these markets. For example, the study by (WU, 2013), which was devoted to the capital markets of G-7 countries, showed the non-existence of price bubbles in the Canadian and Japanese markets. The threshold cointegration test was used as a research method (Enders & Siklos, 2001). The research period adopted in this study is between January 1980 and July 2008, and monthly data were used to determine the models. In addition to the quotations of the indices, the study also considers dividends.

However, another study (Ye et al., 2011) addressing the incidence of price bubbles in the stock markets of G-7 countries used the Fourier unit root test and the nonparametric rank test for

cointegration. The research period adopted in the study was set from January 2000 to June 2009, with a monthly frequency. As in the previously cited work, in addition to the index quotations, the study also included dividends. Using the Fourier unit root test, the authors demonstrated the absence of price bubbles in the stock market in Canada, France, Italy and the UK. The remaining three countries were examined using another research approach (nonparametric rank test for cointegration) and no bubbles were confirmed for these countries either. The final conclusion in this work is that the existence of price bubbles has not been confirmed for any of G-7 countries.

Different results to those presented above can be found in the study by (Chang & Xu, 2012). That work confirms the existence of price bubbles for six of the seven countries studied, with the exception of Canada. Importantly, the research period adopted in this work is identical to that used in the earlier study, i.e. from January 2000 to June 2009. This result, confirming the existence of price bubbles in these markets, is evidenced by the use of a different research approach than in earlier works based on the ADL test for threshold cointegration. The study also used monthly frequency data.

Despite the literature review, the author of this article did not manage to find more works in which all the capital markets of G-7 countries are tested for the existence of price bubbles. Instead, there are a number of works that are devoted to several countries or only one of them, and often these are G-7 countries. An example of such a study is the work by (Horváth et al., 2022), in which the authors, supported by the results of the GSADF test, demonstrated the existence of price bubbles in the capital markets of four G-7 countries, i.e. the US, Japan, the UK and France. In this work, the authors used a novel approach to identify the phases of price bubbles but used different research periods for the markets studied (the last 12 years were not studied) and selected those with statistical significance of the results of  $\alpha=0.1$  as points for further analysis. The occurrence of price bubbles in the Japanese stock market was also confirmed in the study by (Hu & Oxley, 2018). When analysing quarterly data, the authors demonstrated the existence of price bubbles in the Japanese stock market in the 1980s. This study also used the GSADF test to identify price bubbles. The same test was used by the authors of a subsequent study (Nguyen & Waters, 2022) to confirm the existence of price bubbles in the US stock market. Impressively, the study analysed the S&P500 index at a monthly frequency from 1871 to 2020. The existence of price bubbles was confirmed in each research cross-section used due to the occurrence of the Spanish Flu of 1917 and the housing bubble around 2008. An almost identical conclusion can be drawn in the context of the Dotcom bubble.



The final conclusion confirming the existence of price bubbles in the US stock market was also reached by (Harvey et al., 2017; Lee & Phillips, 2016; Phillips et al., 2015).

Based on the literature review, few works on the issue of price bubbles in the investment wine market were also found. The first work that examines the occurrence of price bubbles in the wine market is the study by (Jovanovic, 2013). The final conclusion of this work is that there are price bubbles in the market of high-end Bordeaux wines. The rise in the storage-to-consumption ratio was cited as a phenomenon accompanying the price bubble formation. An example of another study is also (Czupryna & Oleksy, 2015), in which the authors analyse one index from the investment wine market - the Liv-ex 50 index. The study was conducted on the basis of monthly data from 1 December 2001 to 28 February 2015. The study found the existence of two price bubbles in 2006-2008 and 2010-2011. Among the reasons for price bubbles in the wine market, the authors point to increased demand from Chinese investors. Further, the study by (Su & Li, 2020) identified the occurrence of four periods of price bubbles in the wine market. This work also focuses on one index representing the investment wine market – the Liv-ex Fine Wine Investables index. The temporal scope of the analysis covers the period from January 1988 to December 2017. The authors of that work also emphasise that the issue of price bubbles in the investment wine market is a topic that has not received much attention from researchers, which was also one of the reasons why that research topic was undertaken.

In light of the literature review conducted, the following research gap was established: Analysis of the investment wine market in the context of the occurrence of Multiple Price Bubbles (MPBs) and their possible co-occurrence with the precious metal and capital markets of G-7 countries. This is because, as shown based on the literature review, no study has been found that is devoted to studying the occurrence of price bubble periods in the investment wine market and their connection to capital markets. In addition, it has been shown that any work addressing bubbles in the investment wine market has focused on single indices and periods of analysis that do not include data for the past five years. The objectives of the analysis were subordinated to the research gap thus outlined and were defined as follows. First, it was determined whether the markets under study have periods of MPB, that is periods when the market value is different from the fundamental value. The definition of a price bubble as a failure to link the market value of an asset to its fundamental value is derived from the rational bubble theory (Diba & Grossman, 1988) and that is the definition that was adopted in the following study. Although Diba and Grossman's (1988) study concerned capital market investments, the definition adopted



was also generalised for other asset classes in subsequent studies (Pan, 2018; Pindyck, 1993). Second, it was determined whether MBP co-occurrence periods could be said to exist for the investments under study, along with the assessment of the strength and statistical significance of such a relationship. Third, a comparison was made in terms of the duration of the MBP periods. Objectives defined in this way will enable the following resulting research questions to be answered:

RQ1: Are there periods of price bubbles in the investment wine market, represented by leading indices?

RQ2: How can the price bubbles occurring in the investment wine markets be characterised in terms of duration relative to the other investments analysed?

RQ3: Are there any correlations between indices representing different cross-sections of investment wines and the G-7 national capital markets indices regarding the co-occurrence of price bubbles?

RQ4: Are there any correlations between indices representing different cross-sections of investment wines and investments in precious metals regarding the co-occurrence of price bubbles?

Knowing the answers to these questions is important for investors who place their funds in these markets. Based on the results of the analysis below, investment portfolio managers and financial analysts will be able to assess whether investments in investment wines are valuable in terms of diversification of the investment portfolio when price bubble periods occur in the analysed markets. The characterisation of the price bubble periods occurring in the investment wine market will also make it possible to assess whether the inclusion of these investments in an investment portfolio contributes to the reduction of investment risk. From a scientific point of view, the following study makes a theoretical contribution in the context of the possible co-occurrence of price bubbles in the analysed markets.

### **3. Data and methodology**

For the study, data for nine wine investments, three precious metal investments and seven major indices for stock markets from G-7 countries was used. Data for wine investments was taken from the Liv-ex stock exchange website, for commodities investments - from the World Bank website, and for the stock indices - from investing.com. The exact names of the indices are



shown in Table 1 in the next section of the study. The selection of these investments was determined by the research questions. It should be noted here that in the case of investment wines, the Liv-ex exchange, the data of which was used, publishes the widest range of indices in this area that reflect investor sentiment. On the other hand, investments in precious metals were chosen due to their popularity as a safe haven (Baur & Lucey, 2010; Baur & McDermott, 2010) during periods of financial turmoil, which will provide an opportunity to compare wine investments with another, more recognised category of alternative investments. Moreover, in the context of being able to make a comparison between wine investments and other forms of investments, the focus was on the capital markets of G-7 countries, which represent the most developed capital markets and are the main form of traditional investment.

The research period adopted in the study results from the availability of data used for the analysis, obtained from the Liv-ex exchange, and covers the period from December 2003 to March 2022. The analysis used monthly data. Again, this was affected by the availability of data from the Liv-ex exchange, with 220 monthly observations being available for each of the nineteen investments. The length of the time series is important in setting the parameters for the Generalized Supremum Augmented Dickey-Fuller (GSADF) test, which was used to assess the occurrence as well as determine the beginning and end of periods called price bubbles.

The GSADF test (Phillips et al., 2015) is a modified version of the SADF test (Phillips et al., 2011), which in turn is derived from a test that examines the stationarity of the ADF time series (Dickey & Fuller, 1979). As the study shows, the GSADF test is currently the best form of testing the occurrence of price bubbles because its design considers the moving end window of the test but also different values for determining the beginning of the test window, as highlighted in the study by (Caspi, 2017). In addition, the GSADF test has the advantage over its predecessors in that it does not lose its power when the time series consists of multiple observations and there is more than one price bubble (Khan, Su, & Rehman, 2021). These features are important in the context of the length of the research period (220 observations) assumed in this study.

The process of testing the occurrence of price bubbles (GSADF test) and their determination over time (BSADF test) can be expressed by the following formulas (Phillips et al., 2015):

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

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

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.

After determining the periods of price bubbles, the analysis of their co-occurrence was carried out for those investments for which their occurrence was confirmed. A value of one was assigned for all those months classified as price bubble periods and a value of zero for the remaining months. The phi correlation coefficient was calculated for the variables determined in this way. It was decided to use this measure to assess co-dependence since it is optimal for two dichotomous variables (Akoglu, 2018). The phi coefficient ranges from  $-1$  to  $+1$ , with negative numbers representing negative relationships, zero representing no relationship, and positive numbers representing positive relationships (Allen, 2017). In addition to calculating the value of the phi coefficient, the statistical significance of the relationships was also evaluated.

#### 4. Research results

Based on the study and the results of the GSADF test, the existence of numerous price bubbles was identified in all indices that represent investments in investment wines and precious metals. For the major stock indices, that existence was confirmed for the US, Germany and Italy. The significance of the result obtained for these exchanges was 1%, 5% and 10% respectively, while the statistical significance of 1% was obtained for all indices representing the investment wine market. Table 1 shows the detailed results of the study, along with the critical values obtained using Monte Carlo simulations, with the number of repetitions being ten thousand.

Table 1 Results of the study – occurrence of multiple price bubbles

No.	Variable	ADF	SADF	GSADF	Comment (base: GSADF test)
1	<i>Critical value sig. level 90</i>	-0.45	1.09	1.85	
2	<i>Critical value sig. level 95</i>	-0.08	1.38	2.11	



3	<i>Critical value sig. level 99</i>	<i>0.59</i>	<i>1.93</i>	<i>2.66</i>	
4	Bordeaux 500	-0.81	8.56	8.56	Rejects H0 at 1% significance level (***)
5	Bordeaux Legends 40	-1.17	7.00	7.00	Rejects H0 at 1% significance level (***)
6	Burgundy 150	5.05	5.8	6.74	Rejects H0 at 1% significance level (***)
7	Champagne 50	6.40	6.4	8.81	Rejects H0 at 1% significance level (***)
8	Italy 100	2.60	2.6	5.48	Rejects H0 at 1% significance level (***)
9	Liv ex Fine Wine 100	-0.71	9.98	9.98	Rejects H0 at 1% significance level (***)
10	Liv ex Fine Wine 1000	-1.47	8.69	8.69	Rejects H0 at 1% significance level (***)
11	Rest of the World 60	2.25	2.25	4.79	Rejects H0 at 1% significance level (***)
12	Rhone 100	1.13	1.35	3.99	Rejects H0 at 1% significance level (***)
13	Gold	-0.75	4.36	4.36	Rejects H0 at 1% significance level (***)
14	Platinum	-1.92	2.98	3.30	Rejects H0 at 1% significance level (***)
15	Silver	-1.81	4.22	4.42	Rejects H0 at 1% significance level (***)
<b>16</b>	<b>CAC France</b>	<b>-1.08</b>	<b>1.01</b>	<b>1.35</b>	<b>Cannot reject H0</b>
17	DAX Germany	-0.82	2.43	2.43	Rejects H0 at 5% significance level (**)
<b>18</b>	<b>FTSE 350 United Kingdom</b>	<b>-1.68</b>	<b>1.35</b>	<b>1.35</b>	<b>Cannot reject H0</b>
19	FTSE Italia	-1.40	0.92	2.10	Rejects H0 at 10% significance level (*)
<b>20</b>	<b>Nikkei 225 Japan</b>	<b>-0.33</b>	<b>0.82</b>	<b>1.71</b>	<b>Cannot reject H0</b>
<b>21</b>	<b>S&amp;P Canada</b>	<b>-0.40</b>	<b>0.45</b>	<b>1.25</b>	<b>Cannot reject H0</b>
22	S&P500 USA	1.79	2.73	2.73	Rejects H0 at 1% significance level

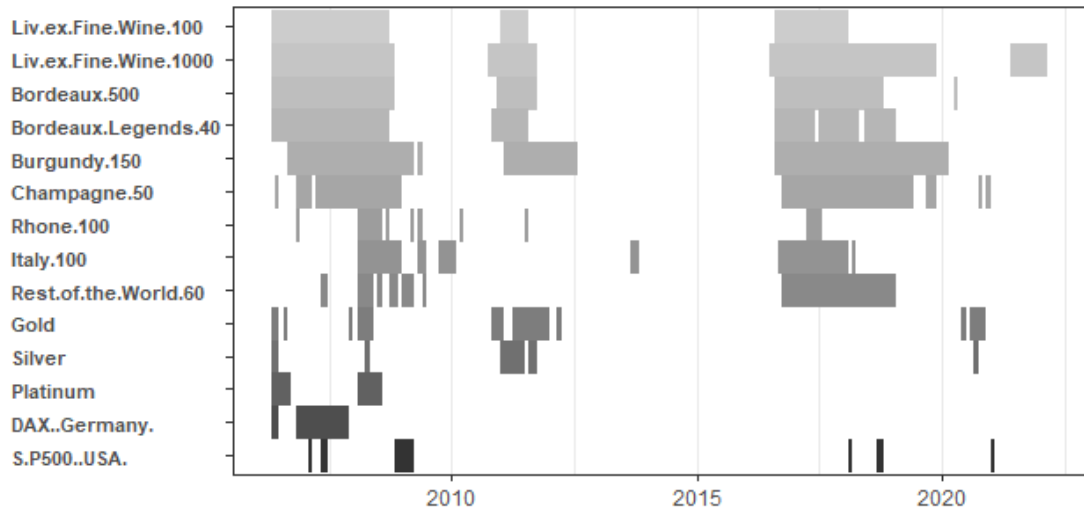
Source: Author's own elaboration.

Based on the data in Table 1, it can be concluded that bubbles are not shown to exist for the four primary stock market indices for G-7 countries. The countries for which the phenomenon was not confirmed were Canada, France, Japan and the United Kingdom (In Table 1 those countries are written in bold). Therefore, the indices for these countries and, additionally, the FTSE index for Italy have been excluded from further analysis due to the low statistical significance of that result.

The periods diagnosed as bubble periods are shown graphically in Figure 1 below.



Figure 1 Temporal identification of the detected price bubbles for which the statistical significance of the result was at least  $\alpha=0.05$ .



Source: Author's own elaboration.

Based on the data presented in Figure 1, it can be concluded that the longest periods of price bubbles occur for the analysed investments in wine for which it is possible to indicate three main periods in which almost all the indices were quoted inconsistently with their fundamental value. Shorter periods of price bubbles were recorded for investments in precious metals, while the fewest of such periods were diagnosed in quotations of the main price indices for Germany.

In Table 2, to extend the information presented in Figure 1, all periods indicated as price bubbles were described for each analysed data series.

Table 2. Results of the study – start and end points of each period defined as a price bubble, with its duration

No.	Index	From ... to... (length in months)
1	Bordeaux 500	from Apr-2006 to Oct-2008 (30); from Nov-2010 to Sep-2011 (10); from Jul-2016 to Oct-2018 (27); from Mar-2020 to Apr-2020 (1); from Aug-2021 to ongoing (8);
2	Bordeaux Legends 40	from Apr-2006 to Sep-2008 (29); from Oct-2010 to Jul-2011 (9); from Jul-2016 to May-2017 (10); from Jun-2017 to Apr-2018 (10); from May-2018 to Jan-2019 (8); from Jan-2022 to ongoing (3);
3	Burgundy 150	from Aug-2006 to Mar-2009 (31); from Apr-2009 to May-2009 (1); from Jan-2011 to Jul-2012 (18); from Jul-2016 to Feb-2020 (43); from Jun-2021 to ongoing (10);

4	Champagne 50	from May-2006 to Jun-2006 (1); from Oct-2006 to Feb-2007 (4); from Mar-2007 to Dec-2008 (21); from Sep-2016 to May-2019 (32); from Aug-2019 to Nov-2019 (3); from Sep-2020 to Oct-2020 (1); from Nov-2020 to Dec-2020 (1); from Jan-2021 to ongoing (15);
5	Italy 100	from Jan-2008 to Dec-2008 (11); from Apr-2009 to Jun-2009 (2); from Sep-2009 to Jan-2010 (4); from Aug-2013 to Oct-2013 (2); from Aug-2016 to Jan-2018 (17); from Feb-2018 to Mar-2018 (1); from Aug-2021 to ongoing (8);
6	Liv-ex Fine Wine 100	from Apr-2006 to Sep-2008 (29); from Dec-2010 to Jul-2011 (7); from Jul-2016 to Jan-2018 (18); from Apr-2021 to ongoing (12);
7	Liv-ex Fine Wine 1000	from Apr-2006 to Oct-2008 (30); from Sep-2010 to Sep-2011 (12); from Jun-2016 to Nov-2019 (41); from May-2021 to Feb-2022 (9);
8	Rest of the World 60	from Apr-2007 to Jun-2007 (2); from Jan-2008 to May-2008 (4); from Jun-2008 to Jul-2008 (1); from Sep-2008 to Nov-2008 (2); from Dec-2008 to Mar-2009 (3); from May-2009 to Jun-2009 (1); from Sep-2016 to Jan-2019 (28); from Oct-2021 to ongoing (6);
9	Rhone 100	from Oct-2006 to Nov-2006 (1); from Jan-2008 to Jul-2008 (6); from Aug-2008 to Sep-2008 (1); from Feb-2009 to Mar-2009 (1); from Apr-2009 to May-2009 (1); from Feb-2010 to Mar-2010 (1); from Jun-2011 to Jul-2011 (1); from Mar-2017 to Jul-2017 (4); from Jul-2021 to ongoing (9);
10	Gold	from Apr-2006 to Jun-2006 (2); from Jul-2006 to Aug-2006 (1); from Nov-2007 to Dec-2007 (1); from Jan-2008 to May-2008 (4); from Oct-2010 to Jan-2011 (3); from Mar-2011 to Dec-2011 (9); from Feb-2012 to Mar-2012 (1); from May-2020 to Jun-2020 (1); from Jul-2020 to Nov-2020 (4);
11	Platinum	from Apr-2006 to Sep-2006 (5); from Jan-2008 to Jul-2008 (6);
12	Silver	from Apr-2006 to Jun-2006 (2); from Mar-2008 to Apr-2008 (1); from Dec-2010 to Jun-2011 (6); from Jul-2011 to Sep-2011 (2); from Aug-2020 to Sep-2020 (1);
13	DAX Germany	from Apr-2006 to Jun-2006 (2); from Oct-2006 to Nov-2007 (13);
14	S&P500 USA	from Jan-2007 to Feb-2007 (1); from Apr-2007 to Jun-2007 (2); from Oct-2008 to Mar-2009 (5); from Jan-2018 to Feb-2018 (1); from Aug-2018 to Oct-2018 (2); from Dec-2020 to Jan-2021 (1); from Feb-2021 to (14);

Source: Author's own elaboration.

Table 2 presents all periods which were detected as price bubbles, based on the GSADF test. Each price-bubble period is described by its start and end points. In parentheses, the duration for each particular price bubble is given. The duration is given in months since monthly data were analysed. If the detected price-bubble period was not finished on the end day of the analysis, then the last price bubble has the description “ongoing”. It should be emphasised that the data from Table 2 are a base for the co-occurrence analysis prepared below. The basic descriptive statistics, i.e., the total value of the months identified as periods of price bubbles, along with their percentage shares in the study period, are shown in Table 3.

Table 3 Characteristics of periods defined as price bubbles

No.	Index	Total length of all periods defined as price bubbles [months]	Percentage of price bubble periods in the length of the period studied	Number of all periods defined as price bubbles	Longest duration of a single price bubble [months]
1	Bordeaux 500	80	36.4%	5	30
2	Bordeaux Legends 40	74	33.6%	6	29
3	Burgundy 150	107	48.6%	5	43
4	Champagne 50	85	38.6%	8	32
5	Italy 100	51	23.2%	7	17
6	Liv-ex Fine Wine 100	69	31.4%	4	29
7	Liv-ex Fine Wine 1000	96	43.6%	4	41
8	Rest of the World 60	54	24.5%	8	28
9	Rhone 100	33	15.0%	9	9
10	Gold	35	15.9%	9	9
11	Platinum	13	5.9%	2	6
12	Silver	17	7.7%	5	6
13	DAX (Germany)	17	7.7%	2	13
14	S&P500 (USA)	32	14,5%	7	14

Source: Author's own elaboration.

The data constitute the basis of the conclusion that periods of price bubbles occur more frequently and last longer on average in the investment wine market than in the other markets under analysis. Among wine investments, the smallest percentage of price bubble periods during the study was observed in the case of the Rhone 100 index, which was also found to have the highest number of such periods. This investment is thus characterised by frequent yet short periods of price bubbles. With regard to the percentage duration of the periods analysed, the Rhone 100 index exhibits similar characteristics to gold investments and the S&P 500 index. Furthermore, the data support the conclusion that investments in raw materials are characterised by much shorter periods of price bubbles than investments in the investment wine market.

In the subsequent stage, the co-occurrence of price bubbles in the analysed markets was examined by means of the calculated values of the phi coefficients. The results of this study, along with their statistical significance, are given in Table 4 (if the result is not statistically significant it is given in bold). The data presented in Table 4 allow assessing whether the markets studied are linked in terms of the co-occurrence of price bubbles.

Table 4. The value of the phi coefficient of the analysed data series for which price bubbles were found.



Variable	Liv-ex Fine Wine 100	Liv-ex Fine Wine 1000	Bordeaux 500	Bordeaux Legends 40	Burgundy 150	Champagne 50	Rhone 100	Italy 100	Rest of the World 60	Gold	Silver	Platinum	DAX (Germany)	S&P500 (USA)
Liv-ex Fine Wine 100	1													
Liv-ex Fine Wine 1000	0.73 (***)	1												
Bordeaux 500	0.81 (***)	0.84 (***)	1											
Bordeaux Legends 40	0.76 (***)	0.79 (***)	0.86 (***)	1										
Burgundy 150	0.56 (***)	0.72 (***)	0.66 (***)	0.6 (***)	1									
Champagne 50	0.57 (***)	0.69 (***)	0.62 (***)	0.58 (***)	0.61 (***)	1								
Rhone 100	0.46 (***)	0.30 (***)	0.37 (***)	0.27 (***)	0.38 (***)	0.32 (***)	1							
Italy 100	0.44 (***)	0.32 (***)	0.44 (***)	0.34 (***)	0.37 (***)	0.43 (***)	0.49 (***)	1						
Rest of the World 60	0.39 (***)	0.48 (***)	0.53 (***)	0.56 (***)	0.56 (***)	0.61 (***)	0.41 (***)	0.64 (***)	1					
Gold	0.21 (***)	0.19 (***)	0.24 (***)	0.24 (***)	<b>0.10</b>	<b>-0.04</b>	<b>0.06</b>	<b>-0.09</b>	<b>-0.10</b>	1				
Silver	0.28 (***)	0.26 (***)	0.31 (***)	0.26 (***)	<b>0.09</b>	<b>-0.05</b>	<b>0.07</b>	<b>-0.08</b>	<b>-0.09</b>	0.62 (***)	1			
Platinum	0.37 (***)	0.28 (***)	0.33 (***)	0.35 (***)	<b>0.10</b>	0.16 (**)	0.27 (***)	0.18 (***)	0.17 (**)	0.42 (***)	0.29 (***)	1		
DAX (Germany)	0.43 (***)	0.33 (***)	0.38 (***)	0.41 (***)	0.20 (***)	0.33 (***)	<b>-0.03</b>	-0.16 (**)	<b>-0.05</b>	<b>0.06</b>	<b>0.11</b>	0.14 (**)	1	
S&P500 (USA)	0.22 (***)	0.18 (***)	0.20 (***)	<b>0.06</b>	0.27 (***)	0.44 (***)	0.22 (***)	0.17 (**)	0.36 (***)	-0.18 (***)	<b>-0.12</b> (*)	- <b>0.10</b>	<b>0.12</b> (*)	1

Source: Author's own elaboration.

Based on the data presented in Table 4, the co-occurrence of price bubbles for the S&P 500 and Bordeaux Legends 40 indices cannot be confirmed. By combining these two investments in an investment portfolio, the risk will be reduced during periods of investment market turmoil and such a portfolio will be protected from extreme changes in rates of return. A similar effect can be achieved by linking the S&P 500 index to silver, platinum or the German DAX index.

The same pattern of the absence of co-occurrence of price bubbles was also observed for the DAX index against the Rhone 100 and Rest of the World 60 indices. The combination of these two investments from the wine market and the DAX index will result in a decrease in the variance of the rate of return of such an investment portfolio during financial market crises.

This consistency in relation to the DAX index was also confirmed for gold and silver investments.

With regard to the Burgundy 150 index, the lack of co-occurrence of price bubbles was observed between this index and all the raw materials analysed in this paper, i.e. gold, silver and platinum. Similar properties in relation to gold and silver were found for the Champagne 50, Rhone 100, Italy 100, Rest of the World 60 indices. This means that investments in raw materials, combined with the indices representing the investment wine market, are desirable elements of an investment portfolio ensuring that investment risk is minimised. In the case of other investment pairs under study, a positive and statistically significant phi coefficient was recorded, suggesting that price bubbles defined in this paper appear in such markets during the same periods. Thus, it is not advisable to combine these investments in a portfolio to minimise investment risk as measured, for example, by the standard deviation of the rate of return.

## **5. Discussion and Conclusions**

The analysis undertaken showed that the investment wine market is characterised by periods in which its estimated value deviates from its fundamental value. Moreover, the determined periods of price bubbles in the investment wine market are longer than in the case of other investments studied. Apart from the Rhone 100 index, the examined investment wine indices were distinguished by the occurrence of periods of price bubbles for a minimum of 20% of the studied time. The highest time percentage of nearly 50%, in which the periods of price bubbles occurred, was observed for Burgundy 150 and Liv-ex Fine Wine 1000. Such long periods of price bubbles as those found in the investment wine market, during which the market value deviates from the fundamental value, should be linked to the fact that wine investments are emotional investments. According to the papers by (Fernandez-Perez et al., 2019; Masset et al., 2021), it is the emotional aspect of the investments that leads to more frequent periods of price bubbles compared to capital markets. After all, the emotions associated with investing in collectibles, which include investment wines, lead to irrational behaviour that causes the market value of the investment to deviate from its fundamental value over a long period of time. Moreover, the failure of wine investments to generate regular dividends leads to a more frequent occurrence of price bubble periods in that market (Masset et al., 2021). What further reinforces periods of price bubbles in the investment wine market is the increased interest of investors from China and broader emerging markets (Czupryna & Oleksy, 2015; Su & Li, 2020). In the context of increasing inflationary pressure in the global economy from 2022 onwards, a

continuation of price bubbles in the investment wine markets, or tangible investments in general, is to be expected. Due to the occurrence of long price bubble periods in the analysed market and the likelihood that this trend will continue, the following recommendation can be made to limit the phenomenon. One way to reduce the length and frequency of price bubbles, as reported by (Dimson et al., 2015), would be to develop a short sale in the investment wine market.

Interestingly, for investments in raw materials, which also belong to the alternative investment market, the occurrence of long periods of price bubbles has not been confirmed. The author of this study associates this situation with the fact that investments in precious metal are not included in the group of emotional investments. In addition, (Fernandez-Perez et al., 2019) also note that wine investments are prone to the occurrence of price bubbles due to low market liquidity, high transaction costs and information asymmetry, as well as that these characteristics are not relevant in the precious metal market, similarly to the capital markets.

This study also supports the conclusion that ambiguous results were observed for wine investments and the G-7 national stock market indices. Firstly, in the case of stock market indices from countries such as Canada, France, Japan, the UK and Italy, the occurrence of price bubbles was not recorded for the selected methodology. Therefore, it is not possible to speak of strength and direction with regard to the co-occurrence of price bubbles in those markets and the analysed investment wine indices. The price bubble periods confirmed to exist in the German and the US stock exchange were not found to coincide with identical periods for the Rhone 100 and Rest of the World 60 indices in the case of the DAX stock exchange, as well as the Bordeaux Legends 40 and S&P500 indices. For those pairs, the calculated co-occurrence measure was statistically insignificant, indicating that there was no correlation between the existence of price bubble periods in those markets. This is a valuable finding for investors, which emphasises the opportunity to diversify a traditional portfolio consisting of shares of companies listed on the said stock exchanges and the wine investments. The advantages of investment portfolio diversification through wine investments are mentioned, for example, by (Sanning et al., 2008). However, no such advantages can be found in the combination of the other wine indices and capital markets in the US and Germany. The phi value was generally low in the case of other wine market indices, but it was also positive and statistically significant, which makes those indices insufficient for the effective diversification of the investment portfolio in times of market turmoil. On that basis, therefore, it cannot be concluded that every



wine investment hedges an investment portfolio during periods of capital market turbulence, which has not been emphasised in academic research to date.

Similarly, inconclusive findings with regard to the co-occurrence of price bubbles were noted for the investments in the wines under study and the investments in the analysed precious metals. The absence of statistically significant relationship was observed in the case of platinum investments, but only when compared to the Burgundy 150 index. This is a surprising conclusion, given the fact that the periods of price bubbles in the platinum market were among the shortest and least frequent in the study. The fact that the platinum market has little exposure to periods of price bubbles was also discussed in the study by (Wahab & Adewuyi, 2021).

With regard to investment in gold and silver, the lack of any link between price bubble periods was demonstrated for the Burgundy 150, Champagne 50, Rhone 100, Italy 100 and Rest of the World 60 indices. Therefore, a combination of those investments in a portfolio will contribute to its resilience to extreme fluctuations in rates of returns, as they are not characterised by the occurrence of analysed periods at the same time. The same cannot be said for other indices under study, namely the Liv-ex Fine Wine 100, Liv-ex Fine Wine 1000, Bordeaux 500 and Bordeaux Legends 40, since in their case, as well as for gold and silver indices, there is a statistically significant positive relationship in terms of the co-occurrence of price bubble periods.

The aforementioned conclusions are undoubtedly crucial for investors, investment portfolio managers, analysts and broadly-defined stakeholders in the investment wine market. The presented results provided an answer to the question posed by the aforementioned stakeholder groups regarding the suitability of wine investment in the diversification of investment portfolios in times of extreme rates of returns. In subsequent steps, it may be interesting to study the co-occurrence of price bubbles in other collectible markets (art, old cars, sports cards or postage stamps) along with wine investment or the stock market indices of the selected countries. In future research, the source of price bubbles detected in this study should also be investigated. Moreover, the same analysis should be prepared using a different frequency of data.

## 6. References

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>

Akoglu, H. (2018). User's guide to correlation coefficients. *Turkish Journal of Emergency Medicine*, 18(August), 91–93. <https://doi.org/10.1016/j.tjem.2018.08.001>

Allen, M. (2017). *The SAGE Encyclopedia of Communication Research Methods*. <https://doi.org/10.4135/9781483381411> NV - 4

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>

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>

Bouri, E. I. (2014). Beyond the negative relation between return and conditional volatility in the wine market: Is fine wine particularly luscious for investors? *International Journal of Wine Business Research*, 26(4), 279–294. <https://doi.org/10.1108/IJWBR-01-2014-0006>

Bouri, E. I. (2015). Fine wine as an alternative investment during equity market downturns. *Journal of Alternative Investments*, 17(4), 46–57. <https://doi.org/10.3905/jai.2015.17.4.046>

Brunnermeier, M., Rother, S., & Schnabel, I. (2020). Asset price bubbles and systemic risk. *Review of Financial Studies*, 33(9), 4272–4317. <https://doi.org/10.1093/rfs/hhaa011>

- Caspi, I. (2017). Rtaadf: Testing for bubbles with EViews. *Journal of Statistical Software*, 81(November). <https://doi.org/10.18637/jss.v081.c01>
- Chang, T., & Xu, Y. Y. (2012). Rational Bubbles in G-7 Countries: An Empirical Note based on the ADL Test for Threshold Cointegration. *Asian Finance Association (Asian) and Taiwan Finance Association (TFA) Joint International Conference*.
- Czupryna, M., & Oleksy, P. (2015). Rational Speculative Bubbles in the Fine Wine Investment Market. *Kwartalnik Kolegium Ekonomiczno-Społecznego. Studia i Prace*, 3(3), 159–172. <https://doi.org/10.33119/kkessip.2015.3.3.12>
- Czupryna, M., & Oleksy, P. (2018). The Effect of an Electronic Exchange on Prices and Return Volatility in the Fine Wine Market. *E-Finanse*, 14(4), 22–35. <https://doi.org/10.2478/fiqf-2018-0025>
- 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>
- Dimson, E., Rousseau, P. L., & Spaenjers, C. (2015). The price of wine. *Journal of Financial Economics*, 118(2), 431–449. <https://doi.org/10.1016/j.jfineco.2015.08.005>
- Enders, W., & Siklos, P. L. (2001). Cointegration and Threshold Adjustment. *Journal of Business & Economic Statistics*, 19(2), 166–176. <http://www.jstor.org/stable/1392161>
- Eyler, R., & Sims, E. N. (1999). Imported Wine Demand and Stock Market Returns. *International Journal of Wine Marketing*, 11(3), 64–84. <https://doi.org/10.1108/eb008701>
- 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>
- Fernandez-Perez, A., Frijns, B., Tourani-Rad, A., & Weisskopf, J. P. (2019). Behavioural heterogeneity in wine investments. *Applied Economics*, 51(30), 3236–3255. <https://doi.org/10.1080/00036846.2019.1566686>



- Harvey, D. I., Leybourne, S. J., & Sollis, R. (2017). Improving the accuracy of asset price bubble start and end date estimators. *Journal of Empirical Finance*, 40(June 2016), 121–138. <https://doi.org/10.1016/j.jempfin.2016.11.001>
- Horváth, L., Li, H., & Liu, Z. (2022). How to identify the different phases of stock market bubbles statistically? *Finance Research Letters*, 46(June), 102366. <https://doi.org/10.1016/j.frl.2021.102366>
- 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>
- Jiao, L. (2017). Macroeconomic determinants of wine prices. *International Journal of Wine Business Research*, 29(3), 234–250. <https://doi.org/10.1108/IJWBR-09-2016-0032>
- Jovanovic, B. (2013). Bubbles in prices of exhaustible resources. *International Economic Review*, 54(1), 1–34. <https://doi.org/10.1111/iere.12000>
- Jurevičienė, D., & Jakavonytė, A. (2015). Alternative investments: Valuation of wine as a means for portfolio diversification. *Business: Theory and Practice*, 16(1), 84–93. <https://doi.org/10.3846/btp.2015.606>
- 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>
- Le Fur, E., Faye, B., & Cardebat, J.-M. (2014). *What do we know about wine as an alternative financial asset*. <http://www.alde.es/encuentros/anteriores/xviecea/trabajos/f/pdf/336.pdf>
- Lee, J. H., & Phillips, P. C. B. (2016). Asset pricing with financial bubble risk. *Journal of Empirical Finance*, 38, 590–622. <https://doi.org/10.1016/j.jempfin.2015.11.004>

- Łęt, B., & Siemaszkiewicz, K. (2020). Looking for alternatives in times of market stress: A tail dependence between the European stock markets and bitcoin, gold and fine wine market\*. *Finance a Uver - Czech Journal of Economics and Finance*, 70(5), 407–430.
- 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>
- Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, 7(1), 77–91. <https://doi.org/10.1111/j.1540-6261.1952.tb01525.x>
- Masset, P., & Henderson, C. (2018). Wine as an alternative asset class. *World Scientific Handbook in Financial Economics Series*, 6(February), 297–335. [https://doi.org/10.1142/9789813232747\\_0013](https://doi.org/10.1142/9789813232747_0013)
- 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](https://doi.org/10.1142/9789813232747_0012)
- Masset, P., Weisskopf, J. P., Cardebat, J. M., Faye, B., & Le Fur, E. (2021). Analyzing the risks of an illiquid and global asset: The case of fine wine. *Quarterly Review of Economics and Finance*, 82, 1–25. <https://doi.org/10.1016/j.qref.2021.06.023>
- Nguyen, Q. N., & Waters, G. A. (2022). Detecting periodically collapsing bubbles in the S&P 500. *Quarterly Review of Economics and Finance*, 83, 83–91. <https://doi.org/10.1016/j.qref.2021.11.005>
- 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>

- Overton, J., & Banks, G. (2015). Conspicuous production: Wine, capital and status. *Capital & Class*, 39(3), 473–491. <https://doi.org/10.1177/0309816815607022>
- Ozgun, 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. (2015a). Inwestycja w wino – ocena sommelierów, rocznik i liczba punktów dystrybucji a wycena. *Kwartalnik Kolegium Ekonomiczno-Społecznego. Studia i Prace*, 3(3), 173–188. <https://doi.org/10.33119/kkessip.2015.3.3.13>
- Potrykus, M. (2015b). Wine – complement or dominant component of the investment portfolio with minimum risk. *Zeszyty Naukowe Uniwersytetu Szczecińskiego Finanse, Rynki Finansowe, Ubezpieczenia*, 2015(74/1), 455–466. <https://doi.org/10.18276/frfu.2015.74/1-39>
- Potrykus, M. (2022). Diamond investments – Is the market free from multiple price bubbles? *International Review of Financial Analysis*. <https://doi.org/10.1016/j.irfa.2022.102329>
- Potrykus, M. (2023). Price bubbles in commodity market – A single time series and panel data analysis. *Quarterly Review of Economics and Finance*, 87, 110–117. <https://doi.org/10.1016/j.qref.2022.12.002>
- Sanning, L. W., Shaffer, S., & Sharratt, J. M. (2008). Bordeaux Wine as a Financial Investment. *Journal of Wine Economics*, 3(1), 51–71. <https://doi.org/10.1017/s1931436100000559>

- 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., & Li, X. (2020). When will bubbles occur in the fine wine market? *Economic Computation and Economic Cybernetics Studies and Research*, 54(1), 141–158. <https://doi.org/10.24818/18423264/54.1.20.10>
- 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., & Lobonț, 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>
- 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>
- WU, L.-H. (2013). Rational bubbles exist in the G-7 stock markets? Threshold cointegration approach. *Romanian Journal of Economic Forecasting*, XVI(4), 32–43.
- Ye, Y., Chang, T., Hung, K., & Lu, Y. C. (2011). Revisiting rational bubbles in the G-7 stock markets using the Fourier unit root test and the nonparametric rank test for cointegration. *Mathematics and Computers in Simulation*, 82(2), 346–357. <https://doi.org/10.1016/j.matcom.2011.08.008>
- 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>