Analysing Price Dynamics in the Whisky Market: Insights into Price Explosivity and Co-explosivity

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Abstract

The dynamics of price explosivity in the whisky market are crucial for investors seeking portfolio diversification, particularly during periods of global economic instability. This article examines thirty-one whisky indices, grouped into three market groups (Market Performance Indices, Distillery Specific Indices, Collector Specific Indices) in terms of the occurrence of price explosivity periods and their co-explosivity. We use GSADF test to analyze price explosivity periods by using weekly data from December 31, 2012 to March 25, 2024. We find that the period most affected by price explosivity in the whisky market spans from 2016 and 2018. Bowmore, Springbank, Glenfarclas Family Cask, Macallan M18 and Macallan M25 show the highest level of price explosivity. We also confirm the strong co-explosivity effect among studied index groups. However, we find that whisky market does not prone to price explosivity during COVID-19 or the Russian aggression in Ukraine, unlike other markets. This stability makes the whisky market a valuable source of portfolio diversification in times of crisis.

Keywords: Whisky investment, price explosivity, GSADF test, co-explosivity

1. Introduction

Over the course of human history, mankind has dedicated itself to the production of alcohol and its related products such as whisky. In the vast alcohol market, investment in whisky has entered the category of alternative investment [1]. The whisky investment market falls under the category of emotional investments. In recent years, the demand for whisky has increased dramatically. According to the Scotch Whisky Association, the export value of Scotch Whisky was worth £6.2bn in 2022 [2, 3]. In the whisky market, Scotland is considered the market leader with 53 bottles every second to around 180 overseas markets. Apart from Scotland, recent years have witnessed a significant rise in whisky production in other countries such as America, Canada and Japan [4]. The increase in whisky production is based on three factors: the rise in wealthy customers, rising demand in developing markets, and the increasing wealth of middle-class customers in the Asia-Pacific region [5].

Importantly, the whisky market is influenced by three groups: investors, collectors and drinkers. Members of each group have different motivations that influence their purchase decisions. For instance, the purchase decision of an investor is mainly influenced by the amount of the future expected rate of return. This should be ensured by the rarity of a given drink, which may be dependent on a specific brand of a distillery. On the other hand, the motivations of collectors

may be related to the desire to collect all bottles from a certain distillery or a certain year [6]. Finally, drinkers influence the whisky market through consumption habits, tastes and trends. Their preferences for specific brands, styles and flavours influence manufacturing, pricing and marketing strategies. Due to data availability, this study focuses on two main groups: collectors and investors. In other words, the main target groups are investors and collectors, and distillery-specific indices and collector-specific indices are used to collect data. The entire analysis was supplemented with a study of the condition of the broadly understood market using indices from the Market Performance Indices group, which means that this text should also prove interesting for researchers of investment markets and owners or managers employed in the sector related to the broadly understood whisky market. This market not only employs thousands of people in Scotland, but also constitutes an important part of trade in many countries around the world. Thomé et al. [7] argued that the United Kingdom and Ireland are the main exporters of this market, while Australia, France, Japan and Spain are the largest importers of whisky. Whereas Latvia, Netherlands and Singapore fall under the re-export category. This highlights that the whisky market structure is complex, thus an interesting subject of scientific research [8].

The whisky market is considered a less mature investment than that in the wine market. Nevertheless, these market segments gain investors' attention considerably [9]. Moreover, the whisky market size was valued at US $62 billion in 2022 and is expected to reach US $110 billion by 2032 [10]. Due to future growth and researcher interest, it is important to address whether on the whisky market there exist periods that can be characterised as price explosivity[1]. In addition to answering the question of whether such periods occur in the whisky market, it was also decided to analyse the connections between the examined market segments. To the best of the authors' knowledge, this study advances into unexplored areas, and its findings will be valuable to various market stakeholders including investors, collectors, producers and investment market analysts.

Our main findings are as follows. First, we identify 14 indices (10 Distillery Specific Indices and 4 Collector Specific Indices) that are immune to explosive price periods. Those indices, when included in the portfolio, are unlikely to affect portfolio risk significantly and can be treated as an interesting, safe source of portfolio diversification. Second, we indicate indices that exhibit short and few periods of price explosivity. The segment solely consists of 8 indices

[1] The concept of a bubble is hard to pin down in the investment market because there is no agreement on how to identify one. To avoid this confusion, we use the term 'price explosivity' instead, which is less controversial. This term describes the rapid growth in asset prices [26].

from the Distillery Specific Indices group. Including these investments in a portfolio may lead to short-term increases in investment risk. Third, the remaining 9 studied indices are prone to frequent price increases or decreases. Eventually, including those investments in the portfolio should be considered after careful risk evaluation. Additionally, we indicate that during events like COVID-19 and geopolitical tensions do not trigger explosivity, establishing whisky as a stable investment during instability periods. Finally, co-explosivity relationships occur, particularly between certain indices, providing information regarding diversification tactics.

The remainder of the article is as follows. A review of the literature related to investing in the whisky market is presented in the next section. Then, the data are described and the research methodology dedicated to the research gap defined above is presented. The next part presents the conclusions from the analysis, and the entire study is summarised in the conclusions section.

2. Theory

Research on the formation of periods of price explosivity is conducted across a wide range of markets. The issue of price explosivity in capital markets, for example, has been studied in [11, 12, 13]. The crude oil market is another which is popular in the price explosivity field [14, 15, 16] as same as gold market [17, 18, 19]. Another example is house market [20, 21]. To the best of the authors' knowledge, there is no article that examines the occurrence of price explosivity periods on the whisky market. However, the whisky market has been the subject of research across different fields, which we briefly describe below.

The prior literature indicates that within the alcohol segment, the whisky market ranks as the second most favourable for investment purposes [22]. The prime reason for this is the higher rate of return than stock or commodity markets. For instance, Moroz and Pecchioli [9] asserted that the rate of return on investment in whisky was four times higher during 2015-2018 in comparison with the wine market. Moreover, Borowski and Matusewicz [22], argued that the values of the correlation coefficients of the whisky market were low (close to zero) compared with other studied capital and commodities markets. Consequently, these features make the whisky market an appropriate tool for implementing the “buy and hold” investment strategy, and contribute to the increase in the effectiveness of the investment portfolio.

The study of Le Fur [23] highlighted the fact of an average positive rate of return in the long term on this market. At the same time, this signals a significant empirical area of variability for annualised returns. The author states directly that the rates of return on the whisky market change dramatically from negative to positive, which may encourage speculation on this

market. It was the results of this study that formed the basis for assessing whether, in the light of significant fluctuations in rates of return on this market, it is possible to define the existence of price explosivity (possibly of a speculative origin) and their mutual relationships. Another conclusion from this study concerns the zero correlation of rates of return between investments in the whisky market, represented by the individual indices of this market. The study was also extended to examine cointegration, which occurs to a greater extent between the studied indices in the short term than in the long term. All of the above-mentioned features indicate the potential value of investing in whisky from the perspective of diversifying the investment portfolio.

The fact is that the factors which determine the price in the whisky market are significantly different from those that influence prices in traditional investment markets or other alternative investment markets [4]. The author mentions the fact that the production cycle and the maturation time of the drink are long as an important factor in the rising price of whisky in recent years, and therefore in the significant increase in rates of return on this market. The recent sudden increase in demand from developing countries cannot be completely satisfied, which directly translates into an above-average price increase, which mainly concerns old whiskies. Another important conclusion from this study, similar to previous works, is related to the indisputable function of diversifying the investment portfolio using investments in whisky. The author concludes that investment in whisky, due to its risk-return profile, can be treated as an independent area of investment assets.

In the determination of the variables that influence the ask price of a bottle of whisky Moroz and Pecchioli [24], the authors used the following features as explanatory variables in the estimated models: whisky age (period given in years between the distillation date and the bottling date), cask strength (equal to 1 if the whisky was bottled without diluting, and 0 in other cases), non-chill filtering (equal to 1 if the whisky was non-chill filtered and 0 in other cases), alcohol content. Two variables were used to describe the alcohol content: the first variable was between 46% and 50%, and the second described the alcohol content above 50%. Other features include the Murray Score, which determines a point assessment of whisky quality on a 100-point scale, as well as a definition of the distillery and bottler variabilities. Importantly, the authors showed that among the variables examined, mixed conclusions can be drawn regarding the impact of the expert assessment used on the ask price. On the one hand, it turned out that the Murray Score variable is not a statistically significant variable in the proposed models, while on the other hand, the authors do not deny the usefulness of this indicator for novice investors in the whisky market. Additionally, the need to improve the

Murray Score was emphasised, as well as the fact that it is possible to obtain econometric models with satisfactory indicators using distillery and bottler variables, which explain the ask price better than the Murray Score.

Pecchioli and Moroz [25] argued that in the whisky market, a collective reputation effect is present, and they assume that this is true also after controlling for variables connected to the distillery's reputation and the production process of the bottles. In particular, Pecchiolo and Moroz [25] discovered, for example, that the average age of distilleries within an appellation impacts the price in a positive way. The authors conclude that their findings are proof of the existence of collective reputation in the case of geographical appellations in the whisky market. Morover, the authors explain that buyers (investors) may consider collective reputation because their knowledge about quality determinants is weak and it is more difficult to possess such knowledge. The authors created a dataset for their research consisting of more than 83 thousand sales records from nine years (2011-2019).

3. Material and methods

In this empirical investigation, we examine 31 indices representing price changes in the whisky market, which are publicly available on the website https://www.rarewhisky101.com/indices. The indices are grouped into three areas, defined as:

- Market Performance Indices (MPI) (abbreviations used in the rest of the work are also given in brackets for this group of indices): Rare Whisky Icon 100 Index (RWI100) and Vintage 50 Index (V50).
- Distillery Specific Indices (DSI): Ardbeg Index, Balvenie Index, Bowmore Index, Brora Index, Bruichladdich Index, Bunnahabhain Index, Caol Ila Index, Clynelish Index, Dalmore Index, Glendronach Index, Glenfarclas Index, Glenfiddich Index, Glenlivet Index, Glenmorangie Index, Highland Park Index, Lagavulin Index, Laphroaig Index, Macallan Index, Port Ellen OB Index, Rosebank Index, Springbank Index and Talisker Index.
- Collector Specific Indices (CSI): Diageo Special Releases Index, Flora & Fauna Index, Glenfarclas Family Cask Index, Manager's Dram Index, Macallan M18 Index, Macallan M25 Index and Rare Malts Index.

Data for all indices are available on a weekly basis, with new data published every Monday. The time period for all examined indices spans from December 31, 2012 to March 25, 2024, corresponding to 587 measurements for each data series. It should be noted that

https://www.rarewhisky101.com/indices also provides data for 9 other indices, which were not analysed in this empirical investigation due to either having a shorter time series (Japanese 100 Index, Single Grain 100 Index, Karuizawa Index, Yamazaki Index, Balvenie Tun 1401 Index, Game of Thrones Index, Hanyu Cards Index, Macallan ESC. Single Cask Index) or a different data frequency (RW Apex 1000). In line with the approach taken by [26], we drop these indices to ensure the analysis covers the longest possible time range.

To better illustrate the research data, Table 1 presents basic descriptive statistics for logarithmic rates of return, which were calculated on the basis of the values of the studied indices.

Table 1 Descriptive statistics of whisky indices

Descriptive statistics	Mean	Standard Deviation	Kurtosis	Skewness	Range	Minimum	Maximum
MSCI World	0.16%	2.24%	9.89	-0.77	31.33%	-15.85%	15.49%
RWI100	0.22%	1.42%	5.75	1.04	15.27%	-5.54%	9.73%
V50	0.22%	1.33%	79.92	6.41	23.65%	-4.26%	19.38%
Ardbeg	0.17%	1.90%	14.68	1.52	25.18%	-9.11%	16.07%
Balvenie	0.24%	2.39%	23.73	2.51	36.76%	-15.21%	21.55%
Bowmore	0.26%	1.55%	14.37	2.61	17.63%	-6.98%	10.65%
Brora	0.29%	2.38%	26.49	3.41	30.26%	-10.03%	20.24%
Bruichladdich	0.15%	2.38%	7.21	1.01	25.90%	-12.00%	13.90%
Bunnahabhain	0.18%	2.50%	12.94	1.57	30.81%	-11.33%	19.48%
Caol Ila	0.17%	2.74%	11.09	1.02	31.03%	-14.99%	16.05%
Clynelish	0.24%	2.69%	37.25	2.65	46.77%	-15.33%	31.44%
Dalmore	0.28%	2.22%	116.37	8.49	41.59%	-6.36%	35.23%
Glendronach	0.25%	2.01%	28.81	3.16	29.21%	-10.19%	19.01%
Glenfarclas	0.11%	2.03%	27.41	0.33	36.22%	-18.88%	17.33%
Glenfiddich	0.13%	1.33%	26.72	0.50	22.14%	-12.85%	9.29%
Glenlivet	0.09%	1.49%	18.22	2.12	19.39%	-7.62%	11.77%
Glenmorangie	0.13%	2.02%	5.95	-0.32	19.12%	-10.40%	8.71%
Highland Park	0.18%	2.02%	13.06	2.10	23.83%	-8.38%	15.45%
Lagavulin	0.15%	2.33%	5.55	0.40	21.60%	-12.08%	9.52%
Laphroaig	0.17%	1.93%	12.97	2.06	22.88%	-7.79%	15.09%
Macallan	0.21%	1.83%	16.45	2.27	22.37%	-5.82%	16.55%
Port Ellen OB.	0.16%	4.34%	55.62	-0.67	97.07%	-51.47%	45.60%
Rosebank	0.21%	3.90%	76.14	4.54	85.26%	-33.12%	52.14%
Springbank	0.29%	1.44%	15.90	3.04	16.58%	-6.96%	9.62%
Talisker	0.18%	1.98%	16.45	0.97	27.69%	-14.94%	12.75%
Diageo Special Releases	0.21%	2.26%	24.41	1.61	39.81%	-17.86%	21.94%
Flora & Fauna	0.08%	2.47%	12.93	1.12	32.42%	-13.72%	18.70%
Glenfarclas Family Cask	0.34%	2.96%	174.73	10.80	63.41%	-10.62%	52.79%

Manager's Dram	0.17%	4.40%	11.44	0.60	54.76%	-25.77%	28.99%
Macallan M18	0.31%	1.86%	6.07	1.17	19.30%	-9.31%	9.99%
Macallan M25	0.25%	1.55%	5.20	1.17	13.54%	-4.91%	8.63%
Rare Malts Index	0.21%	1.47%	21.63	2.82	19.24%	-4.60%	14.64%

Notes: This table provides details of summary statistics of 31 whisky indices and MSCI World Index, containing the information of mean, standard deviation, range, minimum, and maximum value.

Based on the data from Table 1, it can be concluded that in terms of the average logarithmic rate of return, each of the examined indices was characterised by a positive average rate of return ranging from 0.08% to 0.34%. In the case of investment risk, it can be stated that the following indices were also characterised by high risk, measured by the standard deviation of rates of return, exceeding 3 percentage points: Rosebank, Port Ellen OB. and Manager's Dram; there are no indices from the Market Performance Indices group among them. The indices from this group are characterised by the lowest investment risk, not exceeding 1.5 percentage points, which proves the low risk on the broad whisky market. The examined indices are classified similarly in terms of investment risk if the range value is considered as an indicator. Moreover, Table 1 contains data on the kurtosis and skewness of the examined distributions of returns, as well as the values of the minimum and maximum rates of return. For comparison purposes, we also include in Table 1, in the first row, data for the MSCI World Index. The values for MSCI indicate that, in general, MSCI can be described as an investment with a lower average rate of return and higher investment risk, measured by standard deviation and range.

The periods in which the index value deviated from the fundamental value were determined according to the methodology described in [19, 27, 28]. Transforming the approach described in the works above for the needs of the whisky market, the value of the indices examined in this article, reflecting prices on this market, can be written as follows:

$$P_t = P_t^f + B_t \qquad (1)$$

where:

P_t – is the level of an analysed index at time “t” published in https://www.rarewhisky101.com/,

P_t^f – is a fundamental component, a fundamental level of an analysed index at time "t",

B_t – is a explosivity component, a explosivity factor in an analysed index at time “t”.

If $B_t \neq 0$, there is a price explosivity in the whisky market represented by a certain index. Moreover, if $B_t < 0$, then there is a negative explosivity in the market, and for $B_t > 0$, there is a positive explosivity in the market. The price explosivity component can be expressed as follows:

$$B_t = E_t\left[\frac{B_{t+1}}{1+r}\right] \qquad (2)$$

This means that the occurrence of a price explosivity is possible only in period "t" if the maintenance of this component at a level higher than in the given period is also assumed by market participants in the next period, i.e. "t+1". The higher level of the explosivity component in the period "t+1" is additionally estimated considering the discount factor equal to 1+r, where "r" is the investor's assumed rate of return.

In existing scientific research, several possible sources are mentioned as the reason for the emergence and formation of a price explosivity component that is different from zero. These include "herding behaviour" [29], attention cascades created by the media [30], over-optimism or over-pessimism [31], or speculative trading [32]. The above reasons for the formation of price explosivity (or price explosivity) of various origins can be diagnosed using the GSADF test, i.e. Generalised Supremum Augmented Dickey-Fuller, described in the work [33]. The popularity of this test for detecting periods known as price explosivity is described in [34]. The author showed that the GSADF test is the dominant method of detecting price explosivity in works on the commodity market after 2012. Moreover, the strengths of the GSADF test, compared to its previous versions, SADF and ADF, include the detection of multiple price explosivity and maintaining the power of the test for long time series [35]. The above factors are the key reasons why this research methodology was chosen in this work.

The basic GSADF test statistic formula is given below:

$$GSADF(r_0) = \sup_{r_2 \in [r_0,1], r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \qquad (3)$$

where:

r0 - the minimum length of the test window,

r1 - the start of the test window,

r2 - the end of the test window,

ADF - the value of the statistic for the Augmented Dickey-Fuller test [36].

If the value of the test statistic for the tested time series exceeds the value of the critical statistic, which in this work was obtained using Monte Carlo simulations with the number of repetitions equal to 5,000, then it can be assumed that there is at least one price explosivity in the tested time series. It should be emphasised that all calculations in this work were performed using the R program, and the main package that was the basis for detecting periods of price explosivity was the "exuber" package [37]. Importantly, the period of price explosivity or the price explosivity includes periods whose minimum duration is at least 3 analysed periods (i.e. three weeks). Such a minimum period has also been previously defined, for example, in the work [38].

After diagnosing the periods in which price explosivity occurred, a zero-one matrix was prepared. The value of one was assigned to those time units for which the existence of price explosivity was demonstrated based on the GSADF test, and the value of zero otherwise. Indices for which the occurrence of multiple price explosivity was not confirmed were omitted from this analysis. The matrix prepared in this way constituted input data for performing logistic regression in order to examine co-explosivity between the examined indices. The econometric model that was used to examine co-explosivity can be written as [26]:

$$\log\left(\frac{P(Y=1|X)}{1-P(Y=1|X)}\right) = \beta_0 + \beta_i * X_{i,t} + \varepsilon_t \quad (4)$$

where:

Y – is a dependent variable indicating if price explosivity was detected,

$X_{i,t}$ – represents a set of dummy variables (the number of variables is connected with the analysed group, for example, Market Performance Indices),

β_0 – a constant term,

β_i – a coefficient value,

ε_t – an error term.

An identical procedure for finding evidence of co-explosivity is used in [26, 39]. To obtain models with the best fit, assessed by the McFadden R^2 statistic [40], we use the backward-elimination rule for the stepwise regression method, which, for the number of explanatory variables that we use, is an adequate method for our purpose [41].

4. Results and discussion

4.1. Price explosivity on whisky market – GSADF test results

Based on the analysis, it was demonstrated for the 15 examined indices that there was at least one price explosivity at a level of statistical significance equal to at least $\alpha = 0.05$. For fifteen indices, no such periods were found, and for the one tested time series (Bunnahabhain), the statistical significance of the obtained result was $\alpha = 0.10$. The names of the studied indices divided into three areas, along with the statistical significance of the obtained results, are presented in Table 2.

Table 2: Price explosivity in market performance indices, distillery specific indices, and collector specific indices

Index group	1%	5%	10%	Reject	Total
Market Performance Indices	(RWI100, V50)				**2**
Distillery Specific Indices	(Bowmore, Clynelish, Glendronach, Macallan, Springbank, Talisker)	(Brora, Dalmore, Glenfiddich, Glenlivet)	(Bunnahabhain)	(Ardbeg, Balvenie, Bruichladdich, Caol Ila, Glenfarclas, Glenmorangie, Highland Park, Lagavulin, Laphroaig, Port Ellen OB., Rosebank)	**22**
Collector Specific Indices	(Glenfarclas Family Cask, Macallan M18, Macallan M25)			(Diageo Special Releases, Flora & Fauna, Manager's Dram, Rare Malts Index)	**7**
Total	**11**	**4**	**1**	**15**	**31**

Notes: This table shows the occurrence of price explosivity in the three studied groups of indices, including market performance indices, distillery specific indices, and collector specific indices.

As shown in Table 2, for indices that belong to the area of Market Performance Indices and represent a broadly understood part of the analysed market, it can be said that there are price explosivity on the whisky market[2]. In the case of the next two groups of indices examined, this market is heterogeneous. It was not found that the number of DSI and CSI indices was significantly larger regarding indices for which the occurrence of price explosivity was confirmed than for those indices where such a phenomenon was not observed. For the DSI indices group, the number of such indices is similar, i.e. for 10 indices, the occurrence of periods

[2] We present a comparative analysis of ADF, SADF, and GSADF test results for 31 indices in Appendix Table A.1. We also show a graphical analysis of price explosivity in market performance indices, distillery specific indices, and collector specific indices in Appendix B.

of multiple price explosivity was confirmed at a significance level of at least α = 0.05, and for 12 indices from this group, such a phenomenon was not confirmed. In the CSI group, this share was 3 indices and 4 indices, respectively. This is therefore a signal to investors and analysts of alternative investment markets that the whisky market is diverse in terms of the occurrence of price explosivity. Only for the MPI group indices can it be said that this is a market exposed to price explosivity. Detailed studies containing the values of test statistics (also for the ADF and SADF tests) for all tested indices along with the critical values for the GSADF test are presented in Appendix A.

In the next part of the work, only 15 tested indices were further analysed, being those for which the occurrence of multiple price explosivity periods were found at least at the level of statistical significance equal to α = 0.05. Figure 1 below shows the periods in which price explosivity were found for these indices.

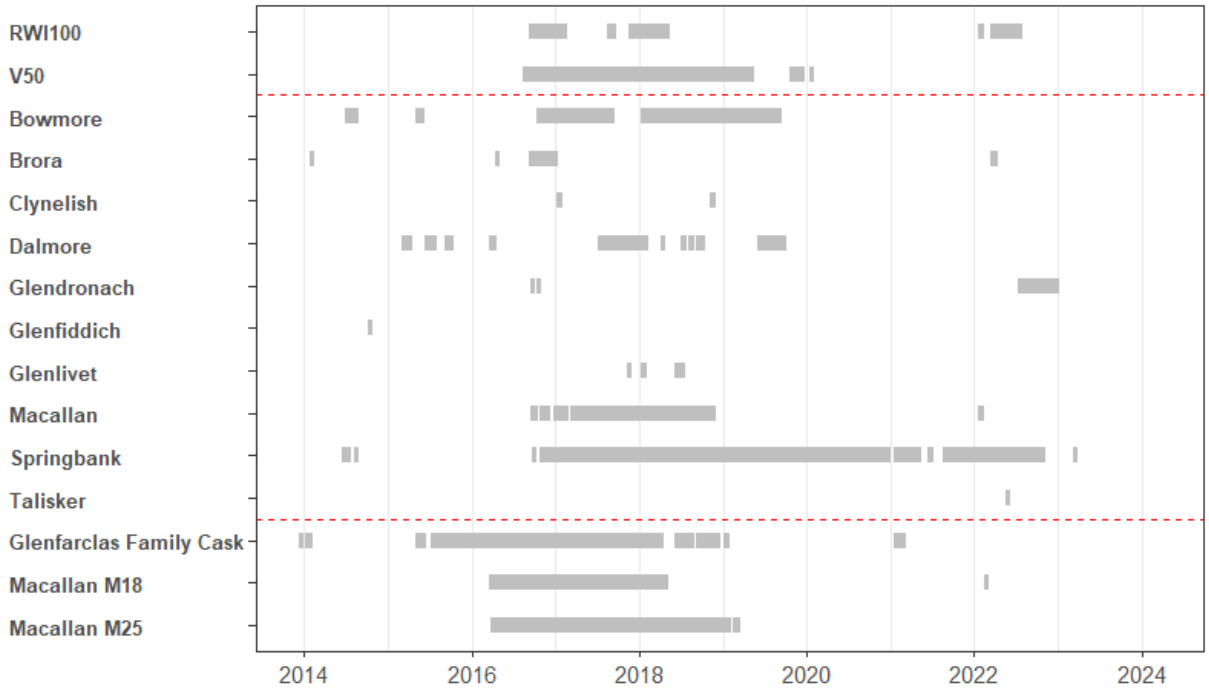

Figure. 1 Data-stamping procedure for indices with the occurrence of price explosivity at least at α=0.05, minimum duration = 3.

The results of the data-stamping procedure are shown in Figure 1. The shaded periods are those indicated as periods with the occurrence of price explosivity. Additionally, there are two horizontal lines on the chart that separate the studied index groups from each other, so that the indices from the MPI group are placed at the top of the chart, then the DSI group in the middle part of the figure and the indices from the CSI group at the bottom (Figure 1). Places that are

shaded on the chart may indicate irrational investing [42, 43], so according to formula (1), these are periods for which the value of the explosivity component is different from zero.

For the indices from the Market Performance Indices group, the first diagnosed price explosivity period concerns the V50 index, starting on 2016-08-08 and lasting continuously until 2019-05-20, for 145 weeks. During this period, the index initially gains 89.9%, reaching a peak on 2018-10-01, and then loses 2.9% of its value over the remaining period of price explosivity. The second diagnosed price explosivity period for this index lasts for 9 weeks, from 2019-10-21 to 2019-12-23, and during this time the index finally loses 3.5%. For the second analysed index from this group (RWI100), 5 periods of price explosivity, longer than three time units, were finally detected. The first such period starts on 2016-09-05 and lasts for 24 weeks until 2017-02-20. Two subsequent periods start in 2017, the first on 2017-08-14 lasting until 2017-09-25, and the second starts on 2017-11-13, but ends on 2018-05-14. Moreover, in 2022, there are two periods of price explosivity for the RWI100 index, the total duration of which is 24 weeks. During these periods, the RWI100 index gained on average 3.4%, with the largest increases during the first (9.8%) and third (8.6%) price explosivity periods. Analysing the data from Figure 1, you can also see overlaps for the main whisky market indices. For 56 weeks, which is 9.5% of the research period, both indices representing the main whisky market experienced price explosivity at the same time. For 69.2% of the research period for these indices, no price explosivity was found at the same time.

In the Distillery Specific Indices group, for ten indices for which the occurrence of periods of price explosivity were confirmed, the Springbank index is characteristic due to the fact that the occurrence of numerous periods of price explosivity was confirmed, exactly 8, with three of them lasting at least 17 weeks. The longest of these periods began on October 24, 2016 and lasted continuously for 219 weeks until January 4, 2021. During this period, the index achieved an increase in value by 109.6%, which was the third highest result for the examined indices. The two remaining long periods of price explosivity began on 2021-01-18 and on 2021-08-16. Equally long, uninterrupted periods of price explosivity were also identified for the Bowmore and Macallan indices. These three distilleries are characterised by the longest periods of price explosivity. Figure 1 also confirms that only short (a maximum of 4 weeks) and few (a maximum of two) periods of price explosivity were detected for the Clynelish, Glenfiddich and Talisker indices.

These three indices differ significantly from the Springbank, Bowmore and Macallan indices in terms of the occurrence of price explosivity. Despite these significant differences between the indicated groups of indices due to the number and characteristics of price explosivity periods, it should be noted that for 33.4% of the research period, price explosivity were detected simultaneously for at least two indices from the DSI group. This situation also occurred for 22.1% and 9.9% of the research period for the simultaneous occurrence of price explosivity for three and four indices, respectively. For 9 weeks (7 times in 2018 and once in 2017 and 2016), price explosivity co-occurred for five indices, being the highest value obtained for the DSI group.

In the group of Collector Specific Indices, the most homogeneous results were obtained due to the occurrence and length of periods of price explosivity. In the case of the Macallan M18 and Macallan M25 indices, two periods of price explosivity were diagnosed per index. For the Macallan M18 index the longer period started on 2016-03-14 and lasted until 2018-05-07, for 112 weeks, during which it increased its value by 176.7%. For the Macallan M25 index, the longer price explosivity started on 2016-03-21 and lasted for 150 weeks until 2019-02-04, during which period the index change was ultimately 129.8%. The longest price explosivity period for the Glenfarclas Family Cask index began on 2015-07-06 and ended after 145 weeks on 2018-04-16. What is significant about this index is the record increase in its value, which increased by 216.2% during this period. In this group of indices, price explosivity co-occurred for at least two indices for 24.4% of the research period, and for 18.4% for 3 indices. The occurrence of price explosivity, especially in the period 2016-2018, is related to the previous observations of Moroz and Pecchioli [9], who also indicated this period as extremely profitable for investors. Market analysts link the boom in the whisky market that started in 2015 with the increasing number of collectors in east Asia, the opening of the online platform Whiskyinvestdirect, and the rising numbers of new auction houses interested in the whisky market [44]. The occurrence of such long periods of price explosivity is also consistent with conclusions [23] about the significant variability of rates of return obtained on this market. The above results are also the basis for examining the co-occurrence of price explosivity using logistic regression.

Table 3 contains the basic descriptive characteristics for the diagnosed periods of price explosivity. The following columns, containing the name of the group of examined indices and the name of the index, also present the number of detected price explosivity periods, their

average duration, total duration in weeks, the maximum length of a single period and the % of the time during which price explosivity occurred.

Table 3: Characteristics of price explosivity

Group	Index	Count	Average [Weeks]	Sum of Duration [Weeks]	Max Duration [Weeks]	% of total time
MPI	RWI100	5	16	80	26	13,6%
MPI	V50	3	52	157	145	26,7%
DSI	Bowmore	4	38	150	88	25,6%
DSI	Brora	4	7	29	18	4,9%
DSI	Clynelish	2	4	8	4	1,4%
DSI	Dalmore	10	9	91	32	15,5%
DSI	Glendronach	3	11	32	26	5,5%
DSI	Glenfiddich	1	3	3	3	0,5%
DSI	Glenlivet	3	5	14	7	2,4%
DSI	Macallan	5	23	116	91	19,8%
DSI	Springbank	8	40	317	219	54,0%
DSI	Talisker	1	3	3	3	0,5%
CSI	Glenfarclas Family Cask	8	25	197	145	33,6%
CSI	Macallan M18	2	58	115	112	19,6%
CSI	Macallan M25	2	78	155	150	26,4%

Notes: This table provides details of characteristics of price explosivity, containing the information of count, average, sum of duration, max. duration, % of total time, price explosivity lasting for at least 3 weeks.

Based on the data in Table 3, it can be concluded that the Brora, Clynelish, Glendronach, Glenfiddich, Glenlivet and Talisker indices (all of which are from the DSI group) are characterised by short (the maximum sum of duration for all detected periods is 32) and few periods which were classified as price explosivity. The total duration of diagnosed periods of price explosivity does not exceed 6% of the research period, and the average length of such a period in this group does not exceed 6 weeks. These indices are therefore an interesting investment for investors who allow only short-term significant price fluctuations and accept moderate investment risk.

For the Dalmore and RWI100 indices, a significant number of periods of price explosivity were recorded, but they are not long-lasting. The average duration of price explosivity for these indices is 9 and 16 weeks, respectively. These indices experienced extreme fluctuations for an almost identical percentage of the time observed. This value is approximately 15%.

Additionally, the maximum length for a single identified price explosivity is 26 (RWI100) and 32 (Dalmore) weeks.

The remaining indices, i.e. Bowmore, Glenfarclas Family Cask, Macallan, Macallan M18, Macallan M25, Springbank and V50, are characterised by over or almost 20% of an occurrence of periods of price explosivity in the total time of the analysed time series. The Springbank index turned out to be record-breaking in this respect, for which the share exceeded 54%. What these indices have in common, is the fact that, the total periods of price explosivity for these indices lasted for over 115 weeks. In this set of indices, the four indices, Bowmore, Macallan M18, Macallan M25, V50, are worth attention due to the fact that a small number (between 1 and 4) of price explosivity were observed, but for usually very long periods, with an average duration exceeding 38 weeks.

4.2. Co-explosivity in whisky indices

In the next step of the study, the co-occurrence of diagnosed periods of price explosivity was analysed using logistic regression. The construction of econometric models was carried out within each of the index groups separately. This means that only data from the same group of indices were used as explanatory variables for a given explanatory variable. Due to the small number of considered indices, from the Market Performance Indices and Collector Specific Indices groups, the results of this study are presented jointly in Table 4.

Table 4: Logistic regression results for market performance indices and collector specific indices

	RWI100	V50	Glenfarclas Family Cask	Macallan M18	Macallan M25
RWI100		2.239 (0.268) ***			
V50	2.239 (0.268) ***				
Glenfarclas Family Cask				2.197 (0.517) ***	2.915 (0.352) ***
Macallan M18			2.197 (0.517) ***		4.384 (0.566) ***
Macallan M25			2.915 (0.352) ***	4.384 (0.566) ***	

	-2.828	-1.391	-1.9	-5.387	-3.460
	(0.21)	(0.111)	(0.143)	(0.584)	(0.287)
const	***	***	***	***	***
McFadden R^2	0.166	0.114	0.434	0.638	0.631

Notes: This table presents the results of co-explosivity in market performance indices and collector specific indices. The symbols "***"; "**"; "*" denote statistical significance at the 0.01, 0.05 and 0.10 levels, respectively.

The results from Table 4 constitute the basis for determining the co-occurrence of periods of price explosivity in the individual analysed index groups. The model built for the Rare Whisky Icon 100 Index (RWI100) and the Vintage 50 Index (V50) indicates the co-occurrence of the studied periods. This means that the presence of price explosivity in one index increases the probability of such periods occurring in the other index from this group. A similar relationship was also confirmed for the Collector Specific Indices group. A total of three indices were examined in this group and it turns out that for each examined index there was a higher probability of price explosivity occurring as a result of their occurrence in the other two indices from this group. All variables used as explanatory factors for both groups of indices turned out to be statistically significant, with the highest considered level of significance equal to $\alpha = 0.01$. This indicates a strong co-explosivity effect of the studied index groups.

Table 5 presents the results of logistic regression for the Distillery Specific Indices group. In this group, a total of ten indices were analysed for which the occurrence of price explosivity was confirmed.

Table 5: Results from logistic regression for distillery specific indices

	Bowmore	Brora	Dalmore	Glendronach	Glenlivet	Macallan	Springbank
				-1.839	1.850	2.390	2.340
Bowmore				(0.650)	(0.687)	(0.303)	(0.376)
				***	***	***	***
			-2.410	1.942		2.143	
Brora			(1.045)	(0.533)		(0.566)	
			**	***		***	
		-2.378			2.194	1.856	
Dalmore		(1.049)			(0.628)	(0.355)	
		**			***	***	
	-1.481	1.619					0.757
Glendronach	(0.696)	(0.537)					(0.403)
	**	***					*
			1.231				
Glenlivet			(0.630)				
			*				

Macallan	2.532 (0.289) ***	1.932 (0.412) ***	1.951 (0.268) ***				3.276 (0.736) ***
Springbank	2.293 (0.376) ***			0.787 (0.394) **		3.453 (0.764) ***	
const	-3.351 (0.340) ***	-3.531 (0.289) ***	-2.266 (0.16) ***	-3.183 (0.307) ***	-5.552 (0.658) ***	-5.866 (0.772) ***	-0.576 (0.106) ***
McFadden R2	0.385	0.139	0.153	0.083	0.238	0.486	0.250

Notes: This table presents the results of co-explosivity in distillery specific indices. The symbols "***"; "**"; "*" denote statistical significance at the 0.01, 0.05 and 0.10 levels, respectively.

Based on the results presented in Table 5, it can be concluded that the indices that influence the occurrence of price explosivity in the largest number of other analysed data series are the Bowmore and Macallan indices. For both of these indices, price explosivity co-occurred with four other examined indices. In the case of the Bowmore index, the occurrence of price explosivity for this index increases the probability of price explosivity for the Glenlivet, Macallan and Springbank indices and at the same time, reduces the probability of such periods forming for the Glendronach index. All these relationships reached the highest significance level considered, i.e. $\alpha = 0.01$. For the Macallan index, the occurrence of a price explosivity period increases the probability of price explosivity on the Bowmore, Brora, Dalmore and Springbank indices. For the next four indices, interactions with three other indices were recorded. The first of such indices is the Glendronach index, in the case of which the occurrence of price explosivity increases the probability of price explosivity for the Brora and Springbank indices and reduces the probability for the Bowmore index. For the Springbank index, there were three interactions with other indices. In all these cases, the occurrence of price explosivity for the Springbank index increases the probability of price explosivity forming for the Bowmore, Glendronach and Macallan indices. Last two indices connected with three other indecies in a case of co-explosivity are Bowmore and Brora. The most resistant indices to the co-occurrence of price explosivity with other examined indices turned out to be the Clynelish, Glenfiddich and Talisker indices. For these indices, when they were explanatory variables, no statistically significant explanatory variables were observed (except for the intercept term). These three indices also did not prove to be statistically significant explanatory variables for any of the other indices. For this reason, Table 5 does not contain columns and rows for these indices. This is primarily due to the fact that for these indices the fewest and shortest periods of

price explosivity were observed, which in turn made it impossible to determine the co-occurrence of price explosivity with other indices.

5. Conclusion

This study explores the crucial dynamics of price explosivity within the whisky market, which holds particular significance for investor seeking to diversify their portfolios, especially amidst global economic uncertainties. It investigates thirty-one whisky indices categorized into three groups, Market Performance Indices, Distillery Specific Indices, and Collector Specific Indices, regarding the occurrence of periods marked by sudden price changes. We analyze these periods by applying the GSDAF test on a weekly data from December 31, 2012 to March 25, 2024. Our main findings for investors and collectors in the whisky market can be summarised as follows. The results show that nearly half of the analyzed indices confirm the occurrence of periods defined as price explosivity at a significance level of at least $\alpha = 0.05$. Using our results, we divide the studied market into three segments based on price explosivity characteristics.

The first segment comprises indices that have not shown any period of price explosivity. Within this category, there are 10 Distillery Specific Indices, which include Ardbeg, Bruichladdich, Caol Ila, Glenfarclas, Glenmorangie, Highland Park, Lagavulin, Laphroaig, Port Ellen OB., and Rosebank. Additionally, there are four indices from Collector Specific Indices: Diageo Special Releases, Flora & Fauna, Manager's Dram, Rare Malts Index. This highlights the presence of investment opportunities in the whisky market that have remained immune to sudden price fluctuations. These investments, once integrated into a portfolio, are unlikely to significantly impact portfolio variance or overall investment risk. In terms of absence of price explosivity, whisky indices can be compared to the capital market in Canada and Japan [13], selected commodities, e.g. silver, aluminium and tin [18] or bananas, cocoa and oranges [34]. However, it is important to note that these results cannot be compared to, for example, a study for the wine investment market, where all nine surveyed indices demonstrated the occurrence of price explosivity [45].

The second segment comprises the indices that exhibit short and few periods of price explosivity. The segment solely consists of indices from the Distillery Specific Indices group, including Balvenie, Brora, Bunnahabhain, Clynelish, Glendronach, Glenfiddich, Glenlivet, and Talisker. Integrating these investments from the whisky market into a portfolio may consequently lead to short-term increases in investment risk. The other whisky market indices exhibit price explosivity, which exceeded a minimum of 10% of the research period, up to

almost 55% of this time in the case of the Springbank index. Consequently, these indices yield significant results, reflecting notable price increases or decreases. However, these current findings align with research on investment wines, particularly regarding the percentage of time exhibiting price explosivity [45, 46]. Importantly, similar to best wines where price explosivity is confirmed for well-known varieties such as high-end Bordeaux wines [47], the longest periods of price explosivity are currently observed for the distilleries with the largest market share (Macallan, Springbank and Bowmore) or brands (Macallan M18 and Macallan M25). This suggests that price explosivity is more pronounced in well-known and valued indices compared to the broader market. This correlates with the investment behavior of less experienced investors, who prioritize reputation when making investment decisions [25].

An interesting findings arises from data-stamping analysis. The main period of price explosivity falls between 2016 and 2018. However, during subsequent crises like the COVID-19 outbreak in 2020 and Russian aggression against Ukraine in 2022, there is no evidence of price explosivity. In contrast, other investment markets, such as cryptocurrencies market [48, 49, 50], crude oil prices and gold prices [51, 52], and stock markets [53], experience price explosivity during these crises. This lack of price explosivity in the whisky market is a valuable insight for portfolio diversification during crisis times.

We also analyse the co-explosivity between indices where the GSDAF test procedure indicates at least one statistically significant price explosivity period. Specifically, for the main indices, the presence of price explosivity in the RWI100 index increases the probability of such periods occurring in the V50 index, and vice versa. Similarly, within the Collector Specific Indices group for Glenfarclas Family Cask, Macallan M18 and Macallan M25, the occurrence of price explosivity periods in one index heightens the probability of similar events in the two other indices.

The Bowmore and Macallan indices experience price explosivity alongside four other indices. When price explosivity occur in the Bowmore index, it increases the probability of occurrence in the Glenlivet, Macallan and Springbank indices, while decreases in the Glendronach index. Similarly, for the Macallan index, when price explosivity occurs, it increases the probability of price explosivity in the Bowmore, Brora, Dalmore and Springbank indices. However, the Clynelish, Glenfiddich and Talisker indices are less affected by co-occurring price explosivity. Therefore, the findings provide valuable insights to investors diversifying their portfolios. This diversification can serve as a hedge during periods of economic uncertainty. Additionally,

considering the lack of price explosivity during crises like the COVID-19 outbreak can inform decisions on portfolio diversification strategies.

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659 **Appendices**

660 A. ADF, SADF, and GSADF test results for 31 indices

661 Table A.1 The values of the obtained test statistics along with the significance level of the
662 obtained results

No.	Group	Index	ADF	SADF	GSADF	Significance level for GSADF
1	MPI	RWI100	-1,44	1,88	2,79	***
2	MPI	V50	-0,92	3,70	3,87	***
3	DSI	Ardbeg	-1,06	1,08	1,42	ns
4	DSI	Balvenie	-0,92	1,22	2,21	*
5	DSI	Bowmore	-1,06	4,32	4,39	***
6	DSI	Brora	-0,95	1,85	2,52	**
7	DSI	Bruichladdich	-1,52	1,33	1,58	ns
8	DSI	Bunnahabhain	-1,41	0,85	2,06	*
9	DSI	Caol Ila	-1,22	1,54	1,74	ns
10	DSI	Clynelish	-0,63	2,44	3,24	***
11	DSI	Dalmore	-0,64	2,49	2,69	**
12	DSI	Glendronach	-0,35	1,68	3,55	***
13	DSI	Glenfarclas	-1,63	1,06	1,18	ns
14	DSI	Glenfiddich	-1,93	0,28	2,41	**
15	DSI	Glenlivet	-1,28	2,31	2,41	**
16	DSI	Glenmorangie	-1,62	0,67	0,89	ns
17	DSI	Highland Park	-0,66	1,68	1,70	ns
18	DSI	Lagavulin	-1,13	1,25	1,80	ns
19	DSI	Laphroaig	-1,47	1,35	1,75	ns
20	DSI	Macallan	-0,60	5,65	5,66	***
21	DSI	Port Ellen OB.	-2,30	-0,04	0,97	ns
22	DSI	Rosebank	-1,16	1,38	1,54	ns
23	DSI	Springbank	0,59	4,45	4,45	***
24	DSI	Talisker	-0,90	1,16	2,90	***
25	CSI	Diageo Special Releases	-1,09	0,48	1,29	ns
26	CSI	Flora & Fauna	-2,06	-0,54	1,70	ns
27	CSI	Glenfarclas Family Cask	-1,06	4,08	4,08	***
28	CSI	Manager's Dram	-1,40	1,60	1,60	ns
29	CSI	Macallan M18	-0,84	6,49	6,49	***
30	CSI	Macallan M25	-0,97	4,39	4,68	***
31	CSI	Rare Malts Index	-1,11	1,36	1,93	ns

663 Notes: The statistical significance of the test was determined by comparing the critical values
664 for the GSADF test, which were obtained using Monte Carlo simulations with the number of
665 repetitions equal to 5,000. If the value of the test statistic for the GSADF test exceeded the value
666 of 1.996, 2.259 or 2.786, it corresponded to a significance level of 0.1, 0.05 and 0.01,
667 respectively.

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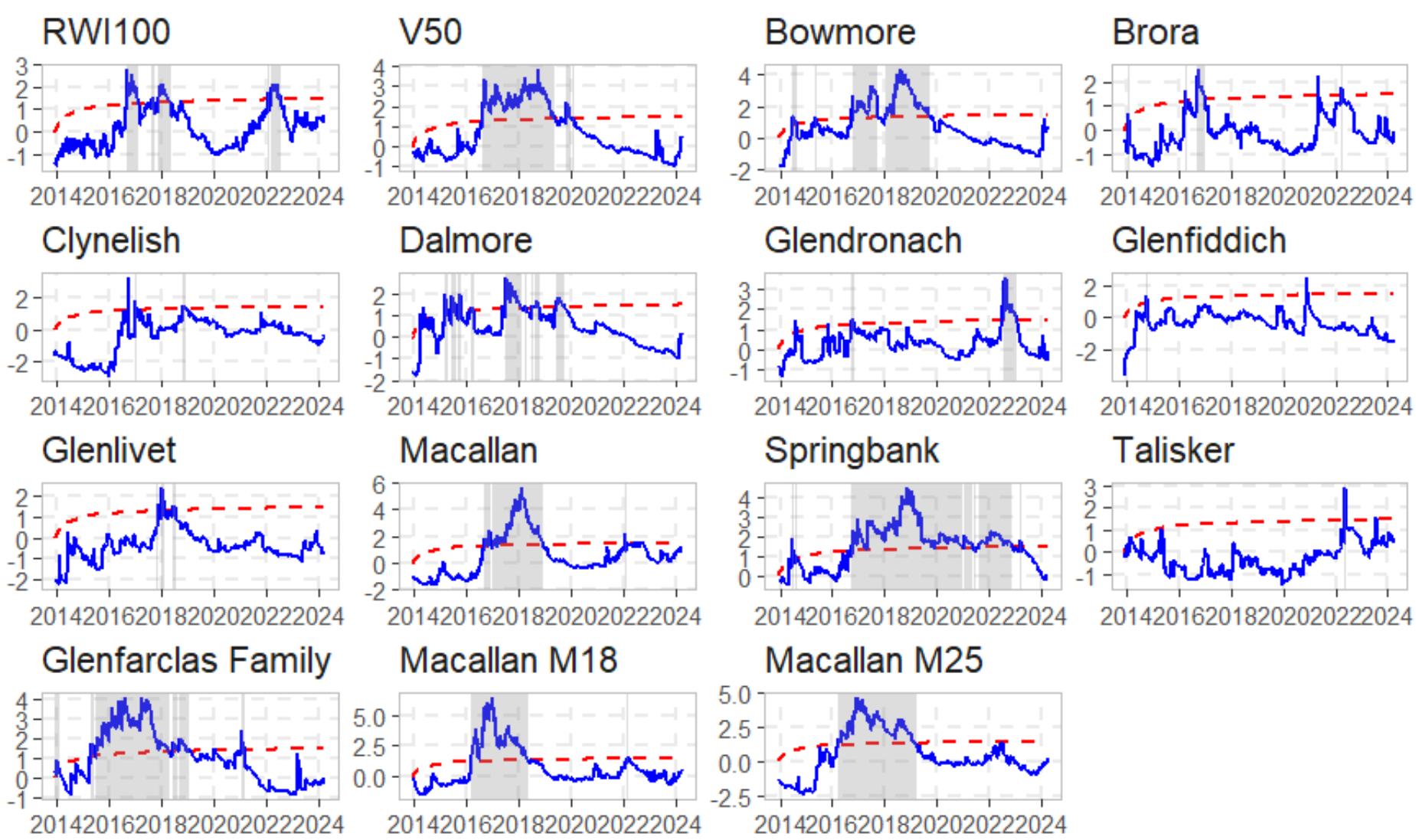
A. Graphical presentation of price explosivity in market performance indices, distillery specific indices, and collector specific indices

Figure. B. 1 GSADF test results



Notes: The blue line shows the individual index, the shaded areas represent explosive episodes. The dashed line indicates the test critical value.