Asymmetric market efficiency of the Eurozone using the MF-DFA: a comparison between global financial crisis and COVID-19 era

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Abstract

Purpose – This research paper aims to explore asymmetric market efficiency of the 13 Euro countries, i.e. Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherland, Portugal, Slovakia, Slovenia and Spain, concerning the period before global financial crisis (GFC), after GFC and period of COVID-19 pandemic.

Design/methodology/approach – Multifractal detrended fluctuation analysis (MF-DFA) is applied to examine the persistence and anti-persistency. It also discusses the random walk behavior hypothesis of these 13 countries non-stationary time series. Additionally, generalized Hurst exponents are applied to estimate the relative efficiency between short- and long-run horizons and small and large fluctuations.

Findings – The current study results suggest that most countries' markets are multifractal and exhibit long-term persistence in the short and long run. Moreover, the results with respect to full sample confirm that Portugal is the most efficient country in short run and Austria is the least efficient country. However, in long run, Austria appeared to be highly efficient, and Slovakia is the least efficient. In the pre-GFC period, Greece is said to be the relatively most efficient market in the short run, whereas Austria is the most efficient market in the long run. In the case of Post-GFC, Netherland and Ireland are the most efficient markets in short and long run, respectively. Lastly, COVID-19 results indicate that Finland's stock market is the most efficient in short run. Whereas, in the long run, the high efficiency is illustrated by Germany. In contrast, the most affected stock market due to COVID-19 is Belgium.

Originality/value – This study will add value to the present knowledge on efficient market hypothesis (EMH) with the MF-DFA approach. Also, with the MF-DFA approach, potential investors will be capable of ranking the stock markets of Eurozone countries based on their efficiency in the period before and after GFC and then specifically in the period of COVID-19.

Keywords Global financial crisis, COVID-19, Efficient market hypothesis, MF-DFA

Paper type Research paper

1. Introduction

The global financial crisis (GFC) and COVID-19 share uncertainty as a significant element after originating in one of the two leading economies (the USA in 2008 and China at the end of 2019). Moreover, both crises severely affect the stock markets, resulting in an economic downturn. Hence, there is a need to consider both situations collectively to analyze the efficiency of stock markets. Therefore, to explore the financial markets' efficiency, a new concept, the efficient market hypothesis (EMH), has been introduced; it has become the investor's favorite device to understand any financial market's quality

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and efficiency. According to Fama (1970), an efficient market (even in its weak form) is if prior information enclosed in price movements is entirely explained in the current prices. Therefore, it is challenging for investors to earn abnormal profits and predict prices based on past statistics. Further, if an efficient market exhibits random walk behavior, the new information is more likely to lessen or exaggerate the prices in an inefficient market, resulting in a severe impact on efficient resource allocation (Ali *et al.*, 2018; Mensi *et al.*, 2017).

The EMH has a significant role in financial literacy in understanding financial markets' behavior and performance. As per the EMH theory presented by "Fama (1970), 1998", any sensible investor can forecast market efficiency with a given market's share price index information. It further stated that if the asset price rapidly shows variation due to the current relevant market information or the asset price is market sensitive, such a market is called a weak-form efficient market. It is not easy for investors to procure abnormal profit in a given situation because of asset price fluctuation, and no one can predict market price and condition. So, the validity of EMH suggests that it is the primary key to predicting such probable gain. There are three significant well-known market situations depending on the market behavior: bear, standard and bull markets. In a stock market, no one can predict the investor's behavior. However, in the other two bear and bull markets, investors' behavior can easily be examined as either aggressive "Greed" or defensive "Fear." In these risky situations, investors can make irrational decisions due to herding behavior, resulting in a variation in stock prices and economic features (Baker and Wurgler, 2006). Many global and regional black swan events have recently distressed the global markets. In discussed techniques, market crashes can occur directly, while the rise in the stock price over a long time confirms asymmetric effects in stock markets (Ni *et al.*, 2015).

Share price indices measure the variation in the stock's value; it states the investor's return on their investment and expresses the variation in the market capitalization. The stock market is a complicated and dynamic structure sensitive to various internal and external variables (Boubaker and Raza, 2017). Exchange institutes and investors are the primary sources of internal influences. Further, external factors that make stock market vulnerable are policies and changes by the governments (Raza and Jawaid, 2014). Also, some crucial events play a major role in affecting stock markets (Mensi *et al.*, 2022). Several researchers have inspected the influence of important events, such as crises, on the stock market's efficiency (Anagnostidis *et al.*, 2016; Mensi *et al.*, 2017; Tiwari *et al.*, 2018). Managi and Okimoto (2013) declared that abrupt "big" shocks, like GFC of 2008, generate structural changes in financial and commodities markets that might result in asymmetric impacts on market efficiency, volatility spillovers and portfolio allocations. Hence, it stimulates the importance of exploring the GFC and COVID-19 effects on the efficiency of these markets. Therefore, in this study, the EMH concept is tested on 13 Eurozone countries with the support of MF-DFA recommended by Kantelhardt *et al.* (2002). The roles of GFC and COVID-19 have been investigated to reflect these countries' stock markets' efficiency by using share price indices data. That is a more flexible and efficient approach than other approaches of analyzing the multifractal (long-term persistent) features of time series having non-stationary properties (Mensi *et al.*, 2017; Bouoiyour *et al.*, 2018).

We have divided the contribution of current study into multiple roles; first of all, this study will add value to the present knowledge on EMH via the estimation of the MF-DFA approach. As the name implies, MF-DFA is based upon the combination of the following two procedures, i.e. "multifractal methods (MF) and detrended fluctuation analysis (DFA)." Mandelbrot *et al.* (1997) considered the MF method a monofractal approach. Conversely, Chen *et al.* (2002) state that DFA is useful in assessing noisy time series and

non-stationary long-term correlations, hence, said to detect monofractal scaling technique. Horvatic *et al.* (2011) claim that the MF-DFA approach expands Kantelhardt *et al.* (2002) DFA method. In this way, it assists in exploring stochastic process's multifractal spectrum for a financial time series (Raza *et al.*, 2021). Some other benefits are: "removal of the monofractal and multifractal behavior of the financial data, assessment of volatility's long-run correlations, degree of time-varying efficiency, and predictability of financial series." Furthermore, this method provides a valid multifractal classification of non-stationary multifractal financial time series. Such attributes of MF-DFA are said to be more interesting than other econometrics approaches. In present research, MF-DFA contributes to the information concerning range memory, random walk behavior, degree of persistency and Eurozone's market efficiency. Secondly, the application of the MF-DFA approach will make potential investors capable enough to rank the stock markets of these Eurozone countries based on their efficiency in the following periods: full sample, pre and post-GFC and period of COVID-19. Thirdly, 13 European countries for the analysis have been targeted. However, prior research by Cao *et al.* (2013) is based on a similar approach, but a point of difference is the selected country. Moreover, prior authors employed MFDFA in analyzing Shenzhen and Shanghai stock markets concerning asymmetric multifractal scaling behavior.

2. Literature review

The literature includes various studies which have explored the efficiency of different markets through MF-DFA. For instance, research conducted by (Tiwari *et al.*, 2018) focused on eight developed countries for investigating their efficiency. The authors employed "the MF-DFA approach" and observed that most markets were highly efficient in the long run. Furthermore, Rizvi *et al.* (2014) claimed that progressive markets are highly efficient; hence, less efficient are the Islamic states' markets. Different results were found by Ali *et al.* (2018) that Islamic markets are found to be more efficient than conventional ones after using the MF-DFA method. Arshad *et al.* (2016) selected the "Organization for Islamic Conference (OIC)" countries and explained that complete efficiency is different across the OIC based on the MF-DFA approach. Stakić *et al.* (2016) examined that the stock market is inefficient after using daily return data from 2006 to 2013. Anagnostidis *et al.* (2016) revealed a significant mean-reverting behavior established after the crisis, and markets are near to random walk behavior before crises.

Rizvi and Arshad (2017) claimed that Japanese stock markets were most efficient during the global crisis period. Moreover, Dow Jones Islamic stock index sectors were targeted by Mensi *et al.* (2017) for testing these markets' efficiency and multifractality. For this purpose, the authors employed MF-DFA. The results indicate that in the long term, efficiency is higher and time-varying. Cao *et al.* (2013) targeted China for the examination of stock markets' uptrend and downtrend multifractality. Thus, the authors used asymmetric MF-DFA. The analysis reveals that uptrends have stronger multifractality than downtrends. In the literature, some studies are available that used the same method in the cryptocurrency, gold, green bonds and conventional bond markets. Such as, Al-Yahyaee *et al.* (2018) emphasize Bitcoin, gold, currency (USD index) and world stock markets' long memory and efficiency. Authors found that long memory and multifractality are present in all investigated return series, and these features are more prominent in the Bitcoin market than in other traditional markets. Likewise, green and conventional bond markets' efficiency was studied by (Naeem *et al.*, 2021). The authors divided the analysis into two periods, i.e. pre and during the pandemic of COVID-19. Hence, to meet this goal, the authors employed the approach of MF-DFA.

Literature consists of several studies that inspect the impact of GFC on market efficiency. For instance, the research investigated 15 emerging European stock markets for their efficiency (Smith, 2012). The results exhibit a severe influence of GFC on the stock markets' efficiency. Kumar and Deo (2013) emphasize the effects of GFC (pre and during crisis) on twenty international financial indices using MF-DFA. It was disclosed that some indices hold significant discrepancies in multifractal degrees in both periods. Majumder (2012) in the context of US and BRICS markets, reveals that before the period of GFC, the US market was highly efficient than others but became inefficient after the crisis. Finally, Mensi *et al.* (2017) considered Islamic stock markets to test the effect of GFC. They employed the MF-DFA approach to examine the efficiency of these markets in the short and long run and concluded that after GFC, most of the markets' efficiency was weakened.

Further, Adu *et al.* (2015) targeted the BRICS countries' stock returns and concluded that China and India's stock markets do not depend on the unit of measurement; on the contrary, Brazil and South Africa's market prediction is dependent on the unit of measurement. Sensoy *et al.* (2015) explored that conventional equity markets are found to be highly efficient than Islamic equity markets. GFC and the succeeding Eurozone sovereign debt crisis underline the higher level of dependency among markets and reveal a degree of asymmetry that exists internally and among markets.

3. Methodology

The share price indices data from June 1994 to August 2022 is used to examine the efficiency of the markets of 13 Euro area countries. The research further divided the full sample into pre-GFC post-GFC and COVID-19 periods.

3.1 Multifractal detrended fluctuation analysis

The two most used methods in the literature are MF-DFA and MF-DCC, but MF-DFA is the most effective and better approach (Shahzad *et al.*, 2017). To detect the scaling behavior that has multifractal features in non-stationary time series, MF-DFA is a better technique. In addition, this method delivers evidence on the long-term memory, level of persistency and efficiency of stock markets. Previously rescaled range analysis "R/S" was used to analyze the long-range correlation behavior of non-stationary time series. However, MF-DFA is a better tool than rescaled range analysis because it avoids the miscalculation of correlation. Furthermore, to analyze the persistence, anti-persistency in the series (mean-reverting process) and random walk behavior, MF-DFA is a better method.

The MF-DFA approach developed by Kantelhardt *et al.* (2002) is applied to examine Eurozone countries' market efficiency. MF-DFA is comprised of five steps as follows.

Let "$\{X_t, t = 1, \ldots, N\}$" be a time series.

Step1. Define the profile

$$Y_k \equiv \sum^{k} t = 1[x_i - \overline{x}], k = 1, \ldots, N, \tag{1}$$

Where $\overline{x}$ represents the average of the entire time series.

Step2. Divide the profile "y_i" into "$Ns \equiv f(N/s)$" non-overlapping segment windows of equal length *s*.

Step 3. Compute the local trend for each of the two N's by the least-squares fit of the series and calculate variance:

$$F^2(s, v) = \frac{1}{s}\sum^{s} i = 1\{y[(v-1)s + i] - y_v(i)\}^2 \quad (2)$$

For "v = 1,2, . . .,$N_{s,}$" and

$$F^2(s, v) = \frac{1}{s}\sum^{s} i = 1\{y[N - (v - N_s)s + i] - y_v(i)\}^2 \quad (3)$$

For $v = N_s + 1, \ldots, 2N_s$.

Step 4. The "*q*th" order fluctuation function "$F_q(s)$" is determined by averaging all segments.

$$F_q(S) = \left\{\frac{1}{2N_s}\sum^{2Ns} v = 1\left[F^2(s, v)\right]^{\frac{q}{2}}\right\}^{\frac{1}{q}} \quad (4)$$

Step 5. Define the scaling behavior of fluctuation functions by analyzing log-log plots "Fq(s)" versus s for each level of "q."

If there is a correlation between the series "xi" in the long term, then "Fq(s)" increases for large values of s, according to power law:

$$F_q(S) \sim S^{h(q)} \quad (5)$$

In general, "h(q)" the exponent describes the criteria for whether the time series is monofractal or multifractal; if "h(q)" is not dependent on q, time series is monfractal otherwise multifractal when "h(q)" is dependent on "q," meaning that the small variation "(q < 0)" and large variation "(q > 0)" of scaling behavior is different. Where "h(q)" is a generalized Hurst exponent, when in the case of stationary series, "h (2)" is the same as the well-known Hurst exponent(H). To examine the correlation in the time series, the scaling exponent "h (2)" is used when "h (2) = 0.5". It explains that series are not correlated and follow a random walk process when "0.5< h (2) <1" indicates long-term persistence series (long-memory), and "0< h (2) >0.5" shows anti-persistence series (mean-reverting process).

4. Empirical results

4.1 Preliminary analysis

Descriptive statistics are explained in Table 1. The results depict that the Jarque-Bera time series of all countries is not normally distributed, indicating the properties of high-pitched peaks and fat-tailed distributions. Furthermore, Augmented Dickey and Fuller's (1979) analysis indicates that all series are stationary at a 1% level of significance. Skewness and Kurtosis results of all series show asymmetry and leptokurtic series.

4.2 Multifractal detrended fluctuation analysis (MF-DFA)

The share price indices' fractal properties are explained by a log-log plot on the length scale and the order of fluctuation effect. A scaling range is vital to decide a linear behavior, as it axes on both lower and upper limits. The current study scaling behavior of the given share price indices is exhibited in Figure 1(a–m). It is clear from these figures that the local slope of these 13 countries' plots changes with crossover time scale (logs*) = 3.3 in the case of overall

Table 1.
Descriptive statistics and results of unit root test

	Mean		Maximum	Minimum	Std. Dev	Skewness	Kurtosis	J-B	ADF test
Austria	0.0014	0.0043	0.0672	−0.1731	0.0217	−2.1641	16.9880	2751.45***	−11.19***
Belgium	0.0015	0.0043	0.0477	−0.1182	0.0179	−1.2951	8.9892	546.42***	−11.00***
Finland	0.0024	0.0051	0.1136	−0.1113	0.0277	−0.3689	5.0740	62.18***	−11.35***
France	0.0017	0.0045	0.0478	−0.0878	0.0191	−0.9573	5.4128	121.75***	−11.43***
Germany	0.0016	0.0046	0.0566	−0.1016	0.0208	−1.0672	5.9614	171.01***	−11.27***
Greece	0.0000	0.0007	0.1315	−0.1341	0.0331	−0.0357	4.2883	21.36***	−11.15***
Ireland	0.0019	0.0051	0.0625	−0.1381	0.0218	−1.4515	8.9053	555.68***	−11.11***
Italy	0.0008	0.0023	0.0730	−0.0985	0.0227	−0.5205	5.1158	71.35***	−11.62***
Netherland	0.0016	0.0051	0.0550	−0.1323	0.0202	−1.5389	9.6807	694.34***	−11.73***
Portugal	0.0019	0.0025	0.0584	−0.0959	0.0205	−0.5324	4.9175	61.73***	−13.83***
Slovakia	0.0004	0.0001	0.0897	−0.1418	0.0221	−0.3858	9.8899	616.84***	−15.22***
Slovenia	0.0068	0.0017	1.6809	−0.0898	0.0988	15.8637	269.3924	923.92***	−23.12***
Spain	0.0015	0.0025	0.0595	−0.0761	0.0210	−0.4700	4.1566	28.50***	−11.30***

Note(s): J-B = Jarque-Bera test of Normality, ADF = augmented Dickey and Fuller (1979) test and KPSS = Kwiatkowski *et al.* (1992) test of stationary. *** denotes the rejection of null hypothesis at the 1%"

Source(s): Authors' Estimation, Table 1 by authors

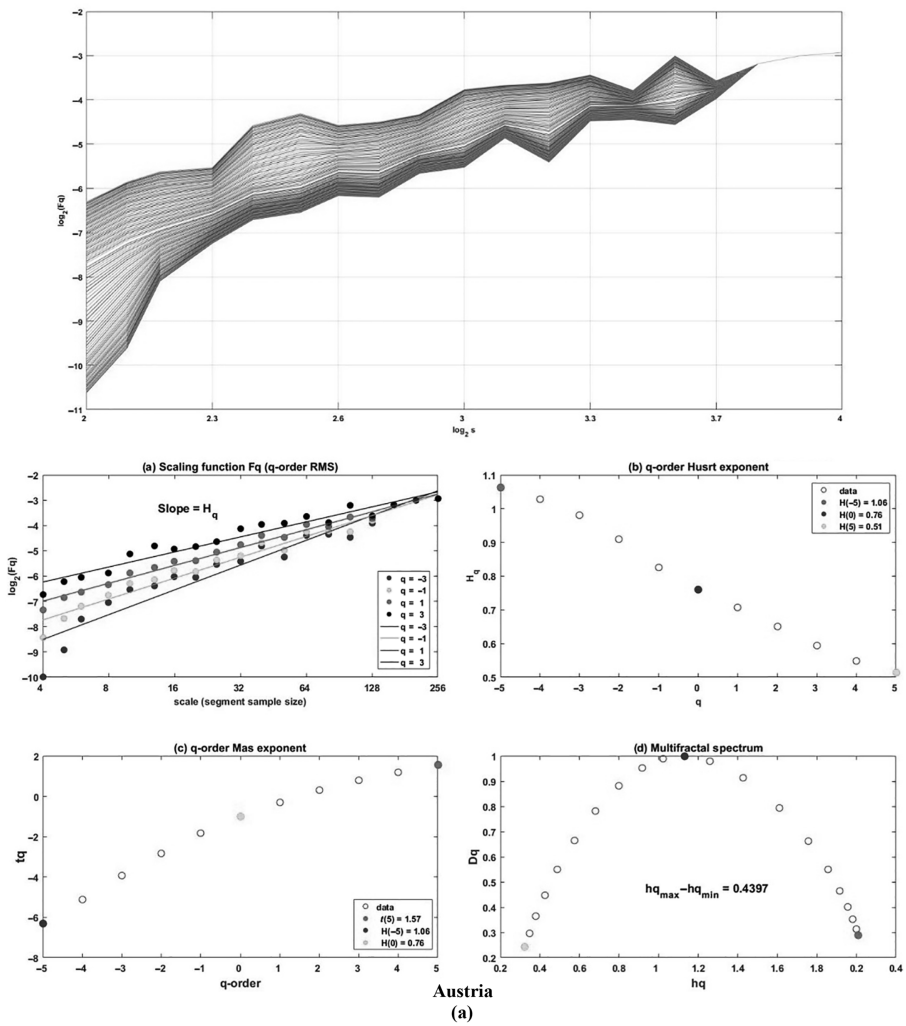

Figure 1.
(a–m) Scaling behavior of the given share price indices

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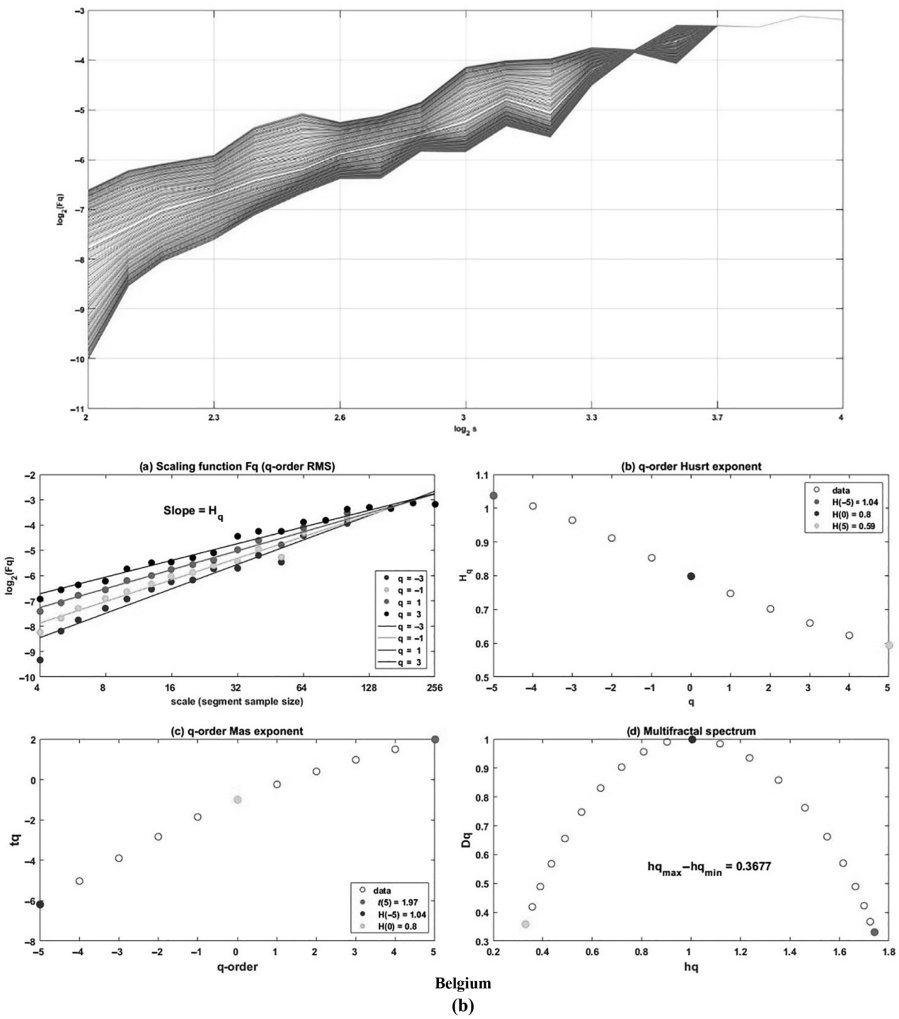

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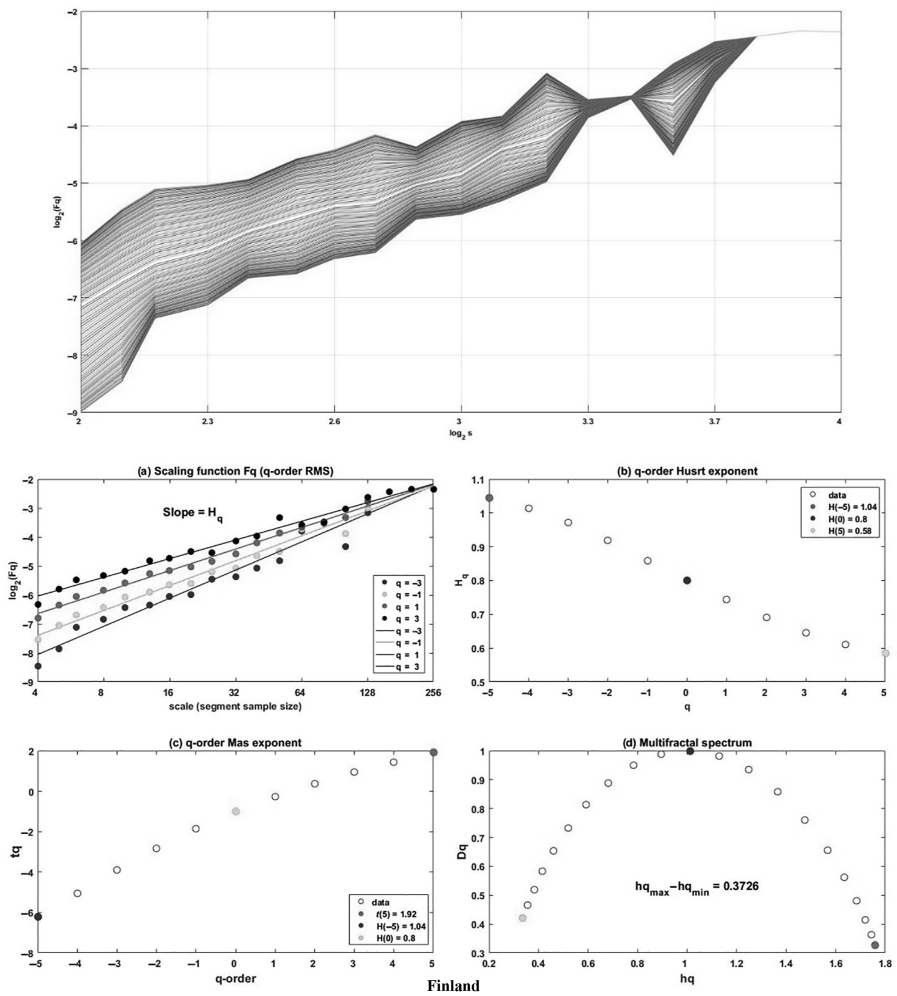

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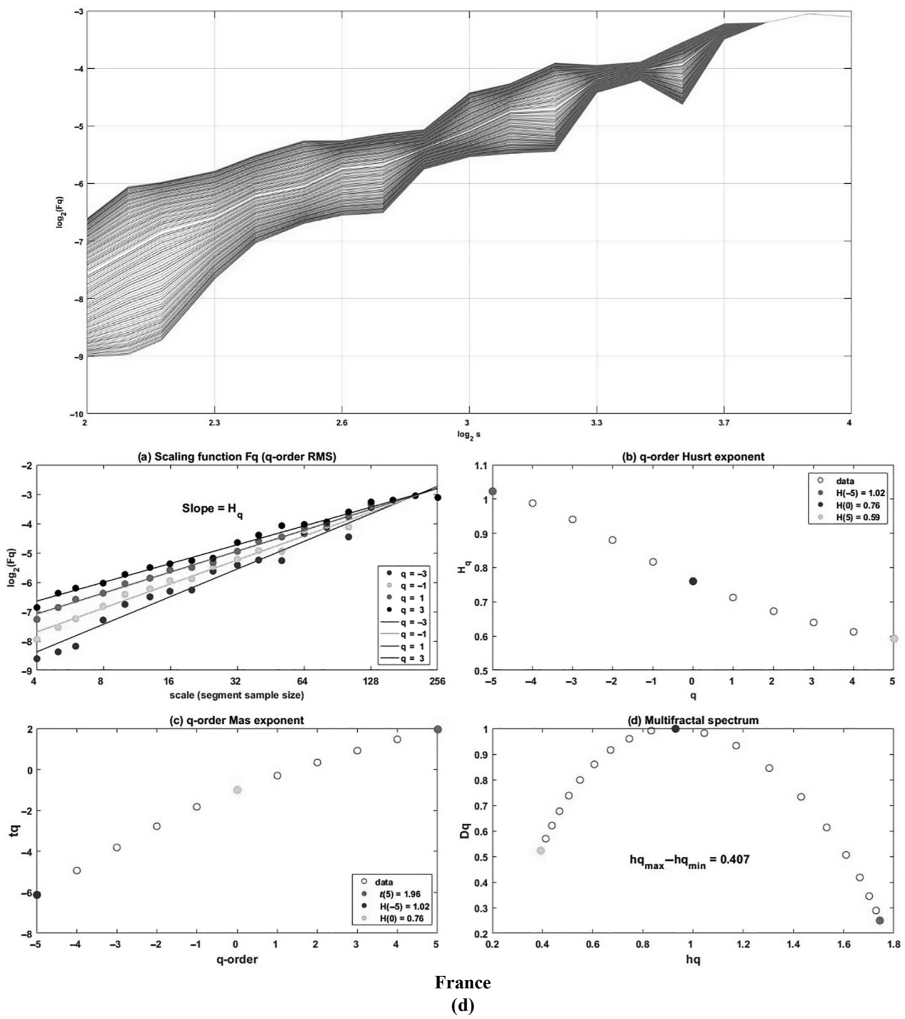

France
(d)

Figure 1.

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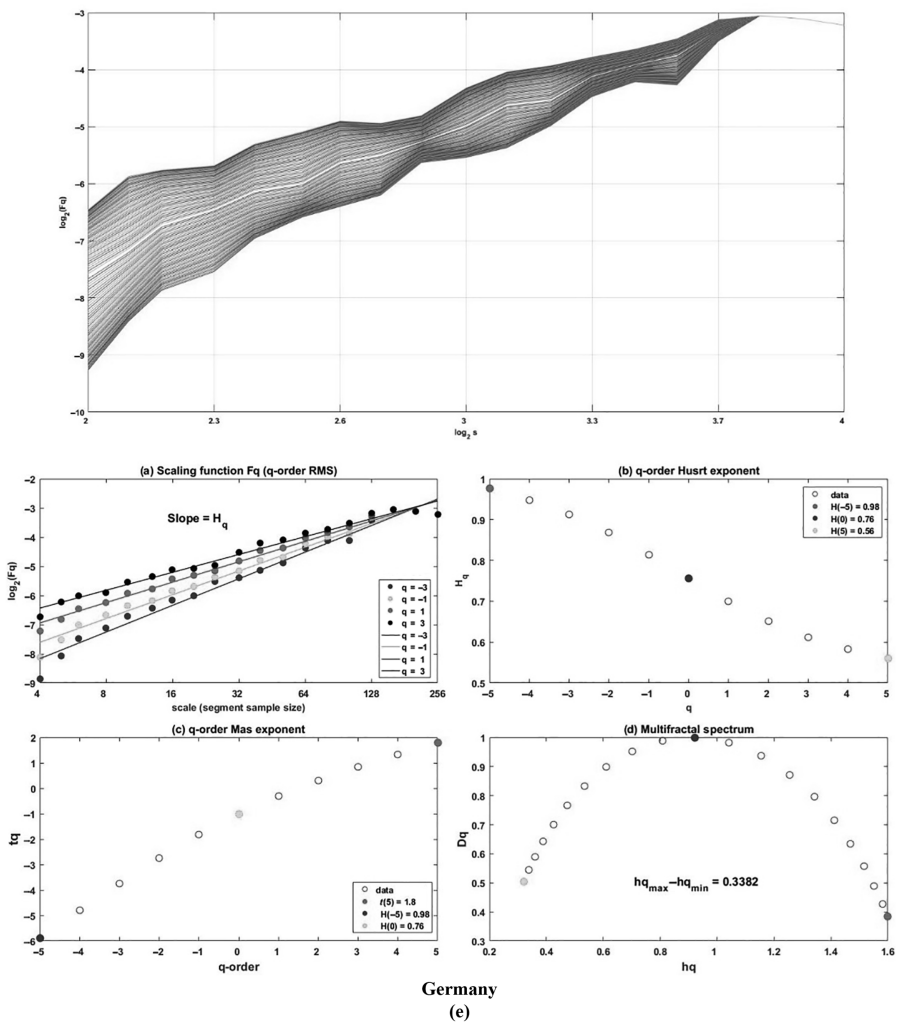

Germany
(e)

Figure 1.

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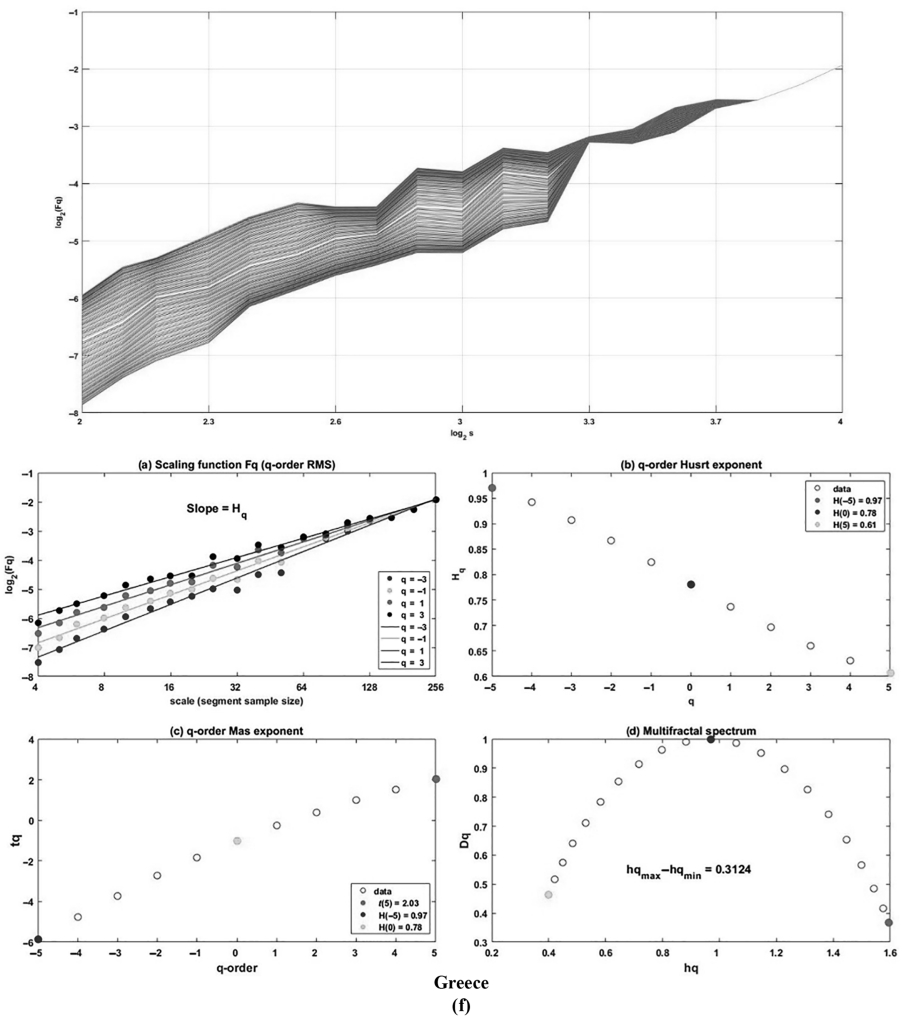

Greece
(f)

Figure 1.

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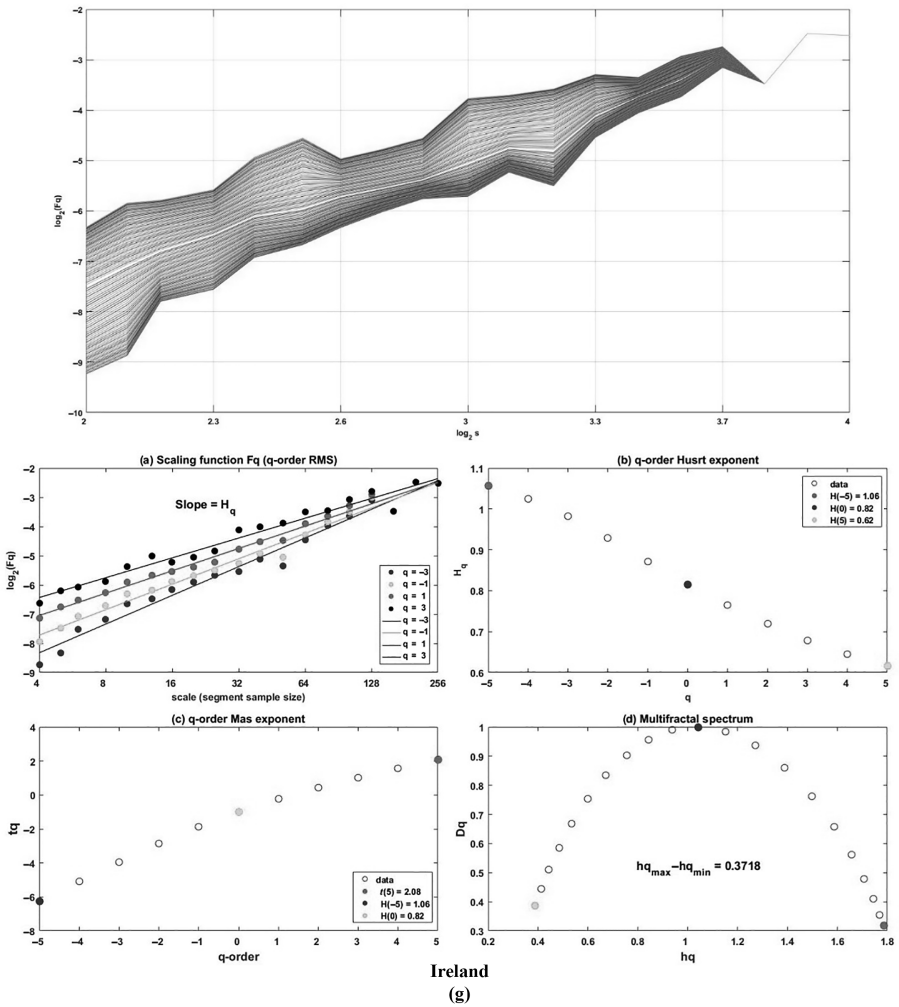

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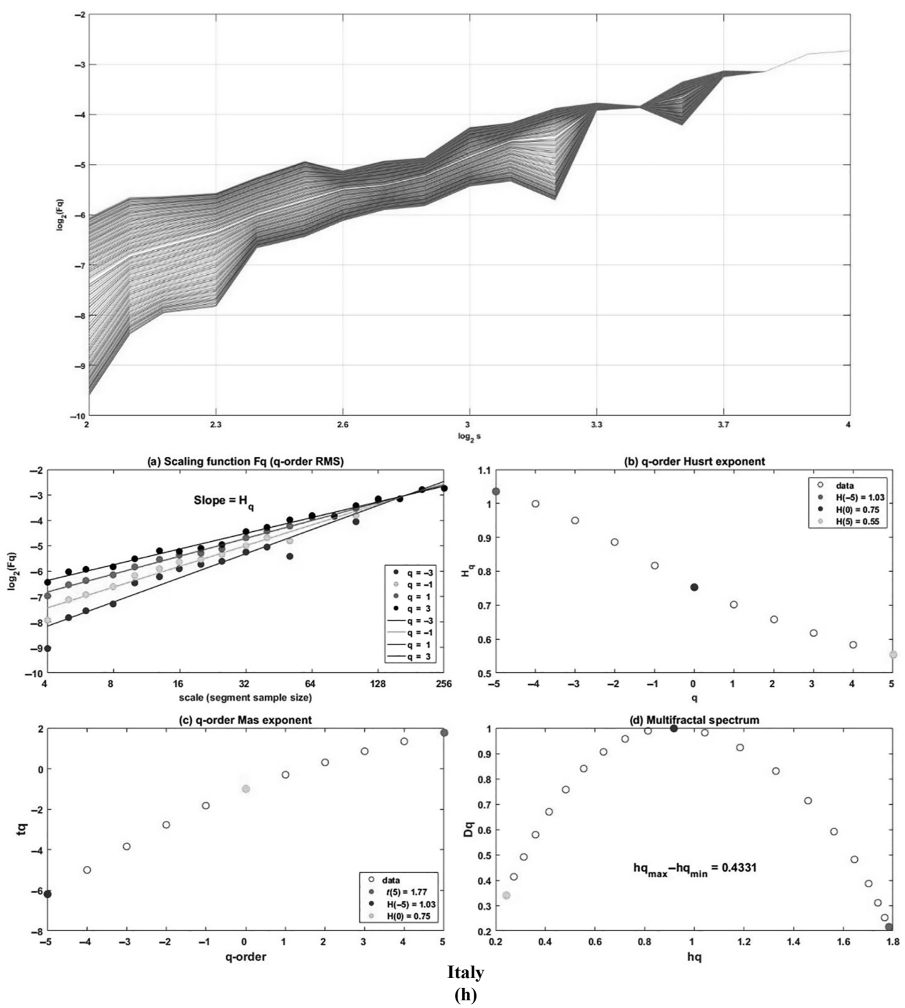

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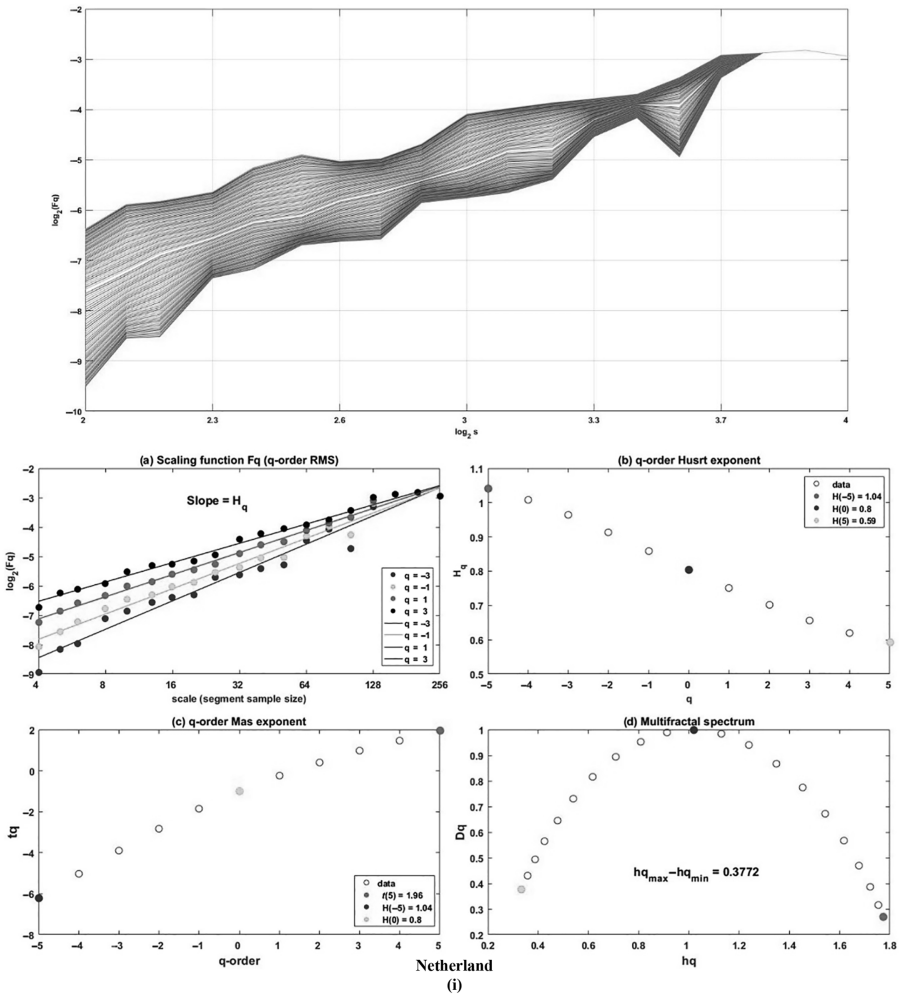

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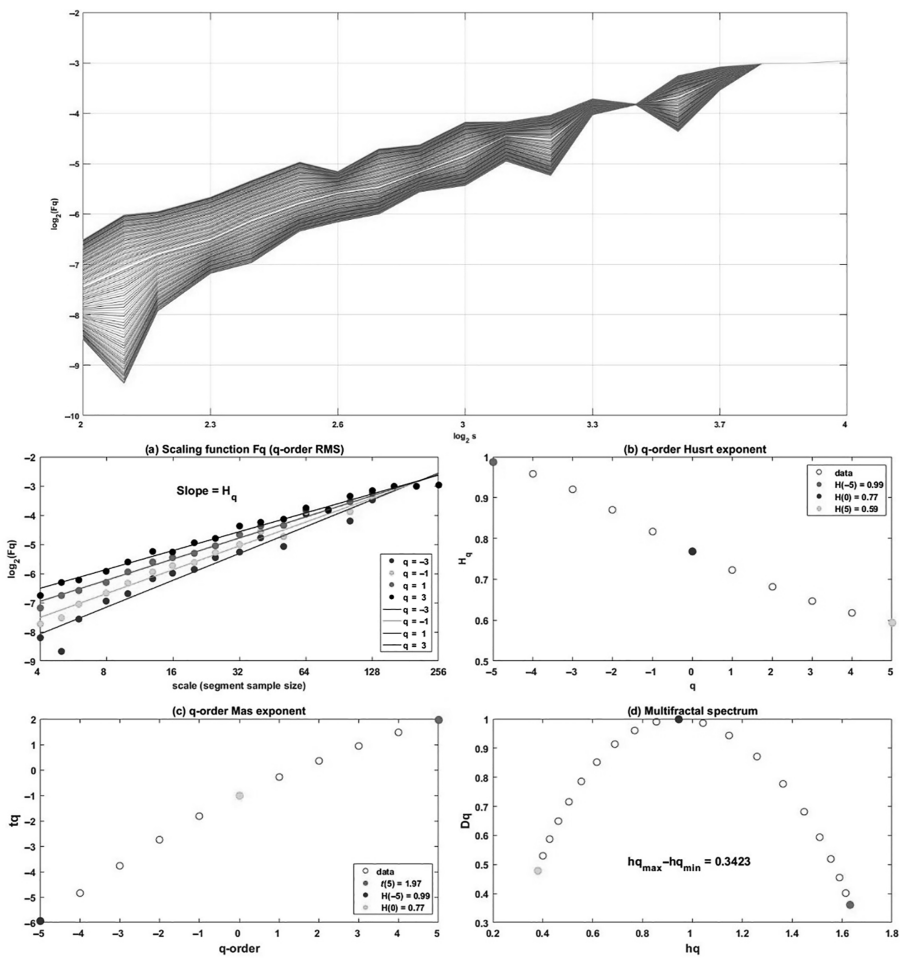

Portugal
(j)

Figure 1.

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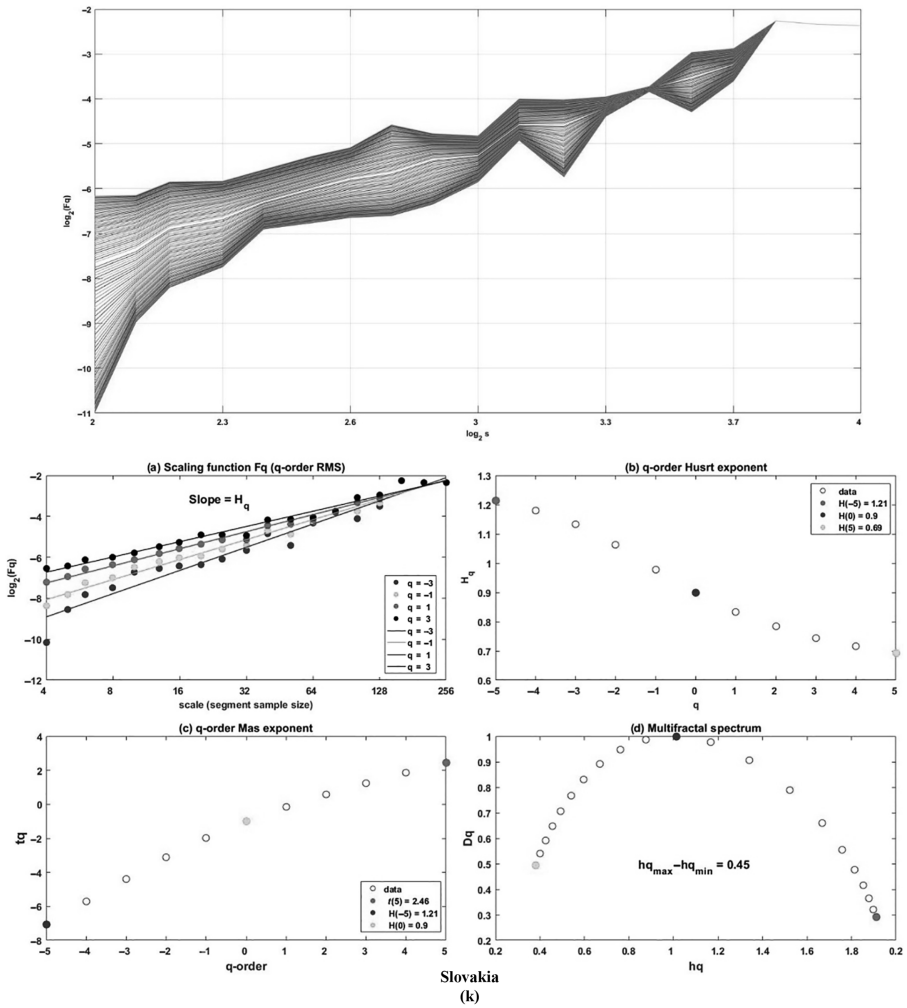

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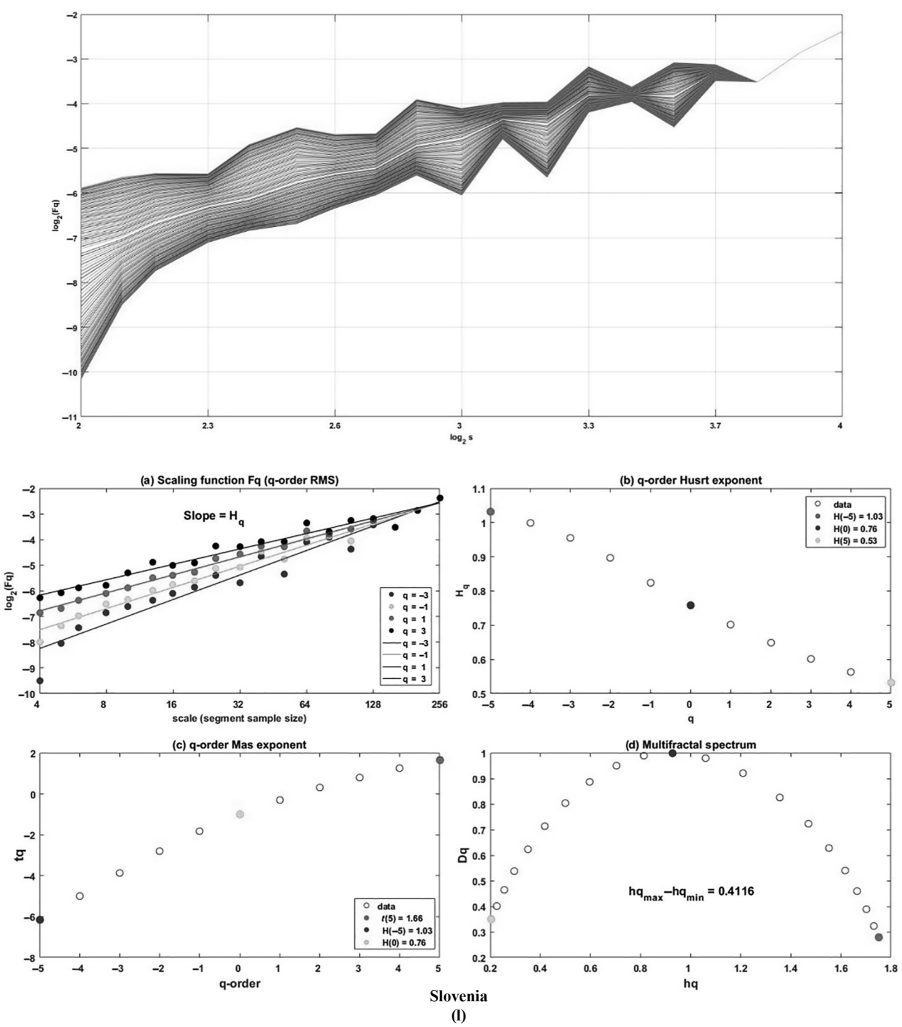

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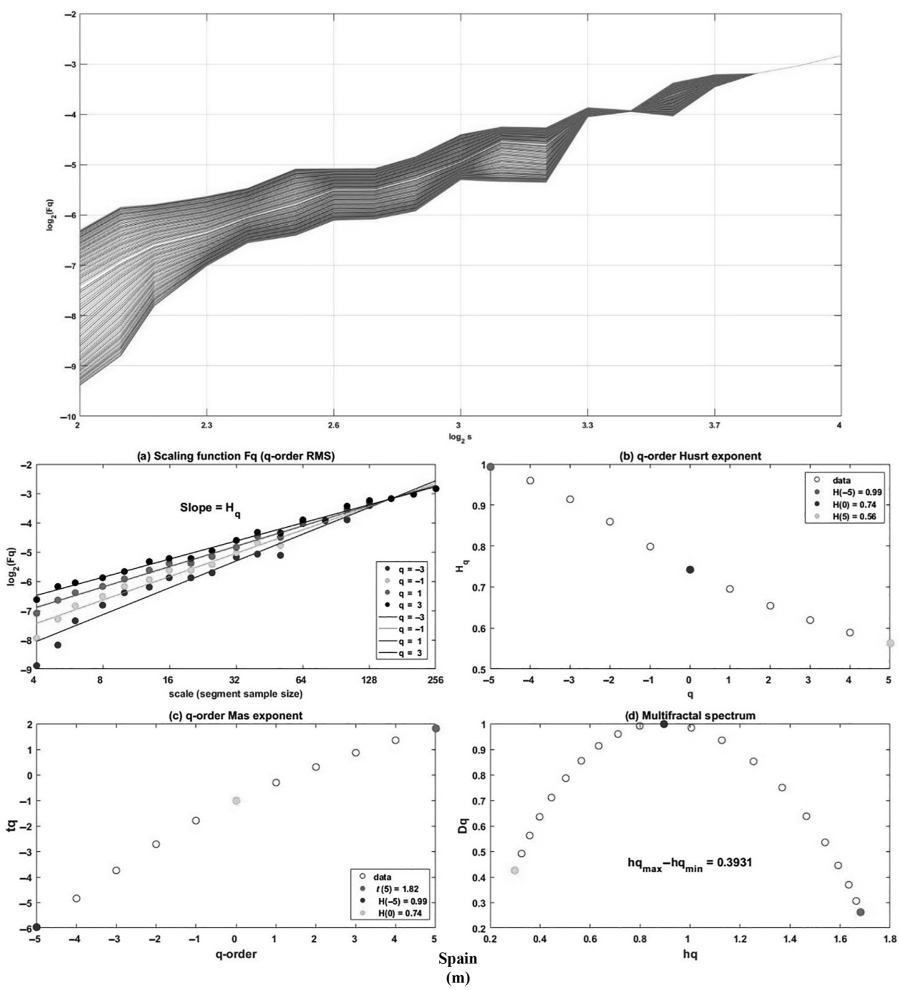

Source(s): Autors' Estimation, Figure 1 (a-m) by authors

Figure 1.

data of all 13 countries, but in this study, we are also analyzing the effect of the GFC, in case of before GFC the crossover time scale for all countries is logs* = 3.9 except in case of Austria, Belgium, France and Germany where crossover time scale logs* = 3.7, but after GFC the crossover time scale for all countries is same that is logs* = 3.3. The crossover point varies at a different time of scale because of the unlike properties of time series. This is the case of two different time scales of stock markets one is the short-run component when s* < s, and the other is the case of the long-run component when s* > s; the MF-DFA approach is used to stud these two-time scales of the stock market of selected 13 Eurozone countries. The q-order Hurst exponent graphs of all 13 countries exhibit proof of multifractality in the time series of these selected countries as h(q) vary with the variation in (q), and there is a decreasing trend in the case of this sample size. The multifractal spectrum graph shows the large arc for the multifractal time series and the small for the monofractal time series. This graph also

calculates the amplitude of the fractal spectrum as it is the difference between hq_{maxi} and $hq_{mini;}$ in our case, Slovakia has the most massive multifractal strength (0.45), and Greece the least multifractal strength (0.31).

4.2.1 Discussion of full sample results. Output Table 2 represents the slopes of generalized Hurst exponents h(q). The upper bound for q is 5, and the lower bound for q is −5 for large fluctuations $q > 0$ and small fluctuations $q < 0$. Moreover, h(q) is not constant and dependent on q, showing that all 13 countries' share price indices have multifractal properties. h(q) explains the scaling behavior of these countries with small and large fluctuations. Further, h(q) for $q < 0$ is higher than h(q) for $q > 0$. This scaling behavior is explained by the stock markets of these 13 countries, estimating long-memory features better in short-term fluctuations than in long-term fluctuations. All h(q) is more significant than 0.5 in both small and large fluctuation, i.e. "$q < 0$ ($q > 0$)," which shows long-term persistence in stock markets of all selected countries. At $q = -5$, Austria is the most constant stock market in the short run, with the series' highest h(q) value (4.021). Greece, in the long run, is chiefly the persistent market with the highest h(q) value (1.019) of the series, and as the h(q) value in both cases exceeds 0.5, both countries are showing more substantial long-term persistence in the short run. To predict the long-term or large fluctuation, we focused on $q = 2$, clearly showing deviation from random walk behavior as all h(q) values are different from 0.5; the same is the case; in the long run, all countries series show long-term persistence as all h(q) are more significant than 0.5. The results of prior literature (Mensi *et al.*, 2019) and (Sensoy and Tabak, 2015) depict similar results. According to Sensoy and Tabak (2015), the literary discourse on random walk behavior has shown negative autocorrelations in the long term. Consequently, in the long run, stock market returns are mean-reverting. Further, in previous studies, it has been found that all series exhibit multifractality; hence, if we compare short and long fluctuations, it is revealed that multifractality is more prominent in short fluctuations than long. It is concluded that investors can predict their future returns based on MF-DFA results, as in our study, most of the countries' markets are presenting long-term persistence. It implies that these markets will be positive in the future if, currently, their returns are complimentary. However, it is also dependent on countries' economic conditions.

4.2.2 Discussion of GFC and COVID-19 results. In Table 3 at $q = -5$, all countries show long-term persistence in the short and long run. Austria has the largest (q) value, the most persistent in the short run, and Portugal has the highest h(q) value, the most persistent in the long run. However, in case of large fluctuation when $q = 2$, all countries have long term persistence except Austria and Slovenia; both countries are mean-reverting or anti-persistence in the long term as $h(q) < 0.5$, which shows that future returns of these two markets are capable of returning to a long-term mean. In the case of Austria and Slovenia, their market scaling behavior is anti-persistence. These results align with past studies' results (Smith, 2012; Sensoy and Tabak, 2015). The findings of Smith (2012) claimed that in the case of the following stock markets "Croatian, Hungarian, Polish, Portuguese, Slovakian, and UK," GFC is highly linked with return predictability. Moreover, the following stock markets "Greece, Latvia, Romania, Russia, and Turkey" observe a minor influence of crisis on weak-form efficiency. Authors also claim that the efficiency of "Croatia, Estonia, Slovenia, and Portugal markets" has deteriorated badly because of the crisis.

Table 4 portrays that at $q = -5$ in the short-term fluctuation, Slovakia is the most persistent country in both the short and long run. At $q = 2$ in the case of long-term fluctuation, most of the countries are showing long term persistency having $h(q) > 0.5$ except Belgium, Finland, France, Germany, Ireland and Italy. While the Netherlands is showing short-term persistence in both the short and long run as h(q) is less than 0.5, these countries' market returns will be negative in the future if it is currently positive. Only two countries' markets show anti-persistent or malicious autocorrelation behavior; after the GFC, seven countries' markets exhibit anti-persistent autocorrelation. These markets' anti-persistent behavior

Country	Austria		Belgium		Finland		France		Germany		Greece		Ireland	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	4.021	0.738	3.043	0.969	2.678	0.902	1.985	0.924	1.939	0.899	1.676	1.019	2.608	0.990
−4	3.896	0.726	2.823	0.957	2.471	0.889	1.881	0.903	2.003	0.881	1.604	0.993	2.468	0.968
−3	3.602	0.715	2.486	0.942	2.166	0.873	1.741	0.878	2.035	0.860	1.515	0.960	2.236	0.944
−2	2.965	0.704	2.016	0.924	1.763	0.853	1.563	0.849	1.945	0.833	1.401	0.918	1.900	0.915
−1	2.018	0.697	1.520	0.899	1.382	0.826	1.355	0.816	1.676	0.801	1.265	0.867	1.513	0.884
0	1.384	0.687	1.163	0.864	1.181	0.786	1.158	0.778	1.338	0.761	1.132	0.808	1.181	0.846
1	1.115	0.652	0.964	0.815	1.144	0.738	1.036	0.738	1.112	0.716	1.039	0.747	0.971	0.800
2	0.983	0.574	0.868	0.753	1.187	0.693	0.991	0.698	1.016	0.671	0.997	0.689	0.878	0.740
3	0.912	0.484	0.831	0.686	1.251	0.655	0.982	0.662	0.978	0.631	0.993	0.638	0.856	0.674
4	0.872	0.411	0.826	0.627	1.307	0.626	0.982	0.631	0.955	0.599	1.008	0.596	0.862	0.617
5	0.848	0.361	0.834	0.579	1.349	0.603	0.982	0.605	0.937	0.572	1.030	0.562	0.873	0.572

Country	Italy		Netherland		Portugal		Slovakia		Slovenia		Spain	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	2.984	0.947	2.494	0.965	1.754	0.967	3.699	1.076	3.532	0.917	2.913	0.896
−4	2.819	0.923	2.336	0.945	1.685	0.944	3.469	1.054	3.356	0.892	2.789	0.875
−3	2.558	0.894	2.122	0.923	1.572	0.917	3.073	1.026	3.036	0.864	2.567	0.851
−2	2.147	0.859	1.839	0.898	1.399	0.882	2.384	0.990	2.457	0.833	2.190	0.824
−1	1.600	0.817	1.498	0.869	1.199	0.841	1.614	0.947	1.631	0.799	1.698	0.793
0	1.168	0.771	1.198	0.830	1.031	0.794	1.272	0.898	1.061	0.756	1.283	0.758
1	0.970	0.723	1.032	0.779	0.918	0.744	1.109	0.850	0.838	0.699	1.050	0.718
2	0.875	0.675	0.972	0.716	0.864	0.694	0.968	0.808	0.731	0.632	0.939	0.677
3	0.795	0.631	0.944	0.654	0.854	0.649	0.848	0.773	0.646	0.572	0.883	0.639
4	0.715	0.593	0.912	0.602	0.868	0.611	0.759	0.744	0.569	0.527	0.851	0.606
5	0.644	0.560	0.875	0.560	0.891	0.580	0.699	0.721	0.501	0.495	0.832	0.578

Source(s): Authors' Estimation, Table 2 by authors

Table 2.
Generalized Hurst exponents of full sample for short and long term components from −5 to 5

Table 3.
Generalized Hurst exponents of before the GFC sample for short and long term components from −5 to 5

Country	Austria		Belgium		Finland		France		Germany		Greece		Ireland	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	3.202	0.753	1.509	0.782	1.647	0.999	1.143	0.951	1.319	0.917	0.894	0.863	1.720	0.878
−4	3.006	0.736	1.488	0.775	1.537	0.955	1.104	0.928	1.359	0.900	0.883	0.852	1.668	0.854
−3	2.682	0.717	1.438	0.767	1.378	0.894	1.063	0.898	1.395	0.879	0.874	0.841	1.572	0.823
−2	2.171	0.693	1.344	0.757	1.172	0.818	1.022	0.861	1.386	0.851	0.863	0.826	1.407	0.786
−1	1.589	0.663	1.206	0.742	0.984	0.743	0.977	0.819	1.276	0.811	0.844	0.801	1.181	0.742
0	1.224	0.620	1.066	0.718	0.887	0.694	0.929	0.774	1.094	0.759	0.822	0.759	0.973	0.690
1	0.989	0.563	0.958	0.683	0.846	0.672	0.892	0.730	0.958	0.701	0.803	0.701	0.820	0.632
2	0.778	0.494	0.882	0.639	0.813	0.656	0.865	0.691	0.888	0.650	0.793	0.642	0.712	0.571
3	0.602	0.424	0.831	0.594	0.782	0.638	0.844	0.659	0.845	0.609	0.794	0.593	0.633	0.511
4	0.483	0.363	0.797	0.555	0.755	0.617	0.828	0.635	0.810	0.579	0.799	0.556	0.572	0.459
5	0.412	0.315	0.775	0.523	0.734	0.598	0.815	0.616	0.782	0.557	0.801	0.528	0.521	0.417

Country	Italy		Netherland		Portugal		Slovakia		Slovenia		Spain	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	1.628	0.986	2.002	0.828	1.816	1.010	1.445	1.004	2.368	0.837	2.089	0.829
−4	1.566	0.965	1.870	0.823	1.750	0.994	1.407	0.959	2.257	0.809	1.956	0.799
−3	1.473	0.941	1.685	0.815	1.623	0.975	1.350	0.902	2.070	0.776	1.768	0.766
−2	1.335	0.914	1.447	0.801	1.396	0.950	1.265	0.840	1.734	0.737	1.515	0.734
−1	1.136	0.882	1.192	0.777	1.119	0.914	1.149	0.787	1.203	0.687	1.221	0.704
0	0.920	0.843	0.989	0.740	0.917	0.863	1.020	0.748	0.802	0.620	0.962	0.675
1	0.765	0.795	0.861	0.692	0.779	0.797	0.899	0.722	0.666	0.537	0.779	0.644
2	0.654	0.742	0.778	0.643	0.687	0.723	0.791	0.701	0.617	0.448	0.640	0.608
3	0.562	0.691	0.721	0.603	0.627	0.656	0.696	0.681	0.580	0.368	0.520	0.571
4	0.487	0.648	0.684	0.571	0.587	0.602	0.619	0.660	0.541	0.306	0.417	0.536
5	0.427	0.613	0.657	0.546	0.559	0.560	0.560	0.640	0.504	0.260	0.334	0.505

Source(s): Authors' Estimation, Table 3 by authors

Country	Austria		Belgium		Finland		France		Germany		Greece		Ireland	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	3.530	0.855	2.695	0.723	2.455	0.689	1.657	0.741	2.075	0.775	1.464	0.850	1.971	0.686
−4	3.418	0.837	2.582	0.706	2.246	0.673	1.565	0.722	1.935	0.751	1.479	0.837	1.867	0.665
−3	3.207	0.814	2.376	0.685	1.944	0.653	1.444	0.695	1.740	0.721	1.502	0.821	1.711	0.639
−2	2.757	0.787	2.000	0.657	1.550	0.628	1.296	0.659	1.478	0.679	1.502	0.802	1.489	0.605
−1	1.929	0.752	1.452	0.621	1.175	0.597	1.139	0.610	1.177	0.623	1.416	0.777	1.223	0.563
0	1.256	0.704	0.996	0.576	0.936	0.562	0.993	0.550	0.926	0.549	1.259	0.747	0.970	0.509
1	1.006	0.638	0.739	0.523	0.785	0.524	0.855	0.487	0.768	0.468	1.121	0.713	0.762	0.442
2	0.910	0.562	0.583	0.466	0.639	0.487	0.723	0.432	0.669	0.392	1.037	0.675	0.600	0.364
3	0.872	0.490	0.469	0.412	0.483	0.455	0.605	0.388	0.595	0.333	1.004	0.639	0.477	0.289
4	0.866	0.432	0.377	0.367	0.339	0.427	0.509	0.356	0.539	0.289	1.004	0.607	0.386	0.225
5	0.875	0.389	0.302	0.331	0.221	0.405	0.434	0.332	0.497	0.257	1.023	0.580	0.316	0.176

Country	Italy		Netherland		Portugal		Slovakia		Slovenia		Spain	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	3.143	0.847	1.478	0.803	1.395	0.840	4.064	1.049	2.655	0.818	3.000	0.908
−4	2.962	0.818	1.405	0.778	1.329	0.818	3.832	1.025	2.497	0.808	2.834	0.878
−3	2.649	0.781	1.299	0.746	1.245	0.792	3.443	0.993	2.218	0.795	2.559	0.840
−2	2.124	0.733	1.147	0.705	1.152	0.760	2.778	0.952	1.769	0.780	2.127	0.793
−1	1.497	0.675	0.961	0.652	1.068	0.723	1.910	0.900	1.255	0.757	1.600	0.736
0	1.097	0.608	0.780	0.586	0.998	0.681	1.263	0.837	0.938	0.712	1.188	0.673
1	0.874	0.538	0.613	0.515	0.930	0.636	0.829	0.768	0.829	0.628	0.957	0.610
2	0.663	0.471	0.432	0.450	0.854	0.592	0.552	0.701	0.808	0.508	0.827	0.552
3	0.426	0.415	0.246	0.399	0.777	0.552	0.401	0.642	0.785	0.394	0.735	0.502
4	0.205	0.370	0.083	0.361	0.707	0.519	0.320	0.595	0.746	0.307	0.661	0.461
5	0.031	0.335	−0.047	0.333	0.650	0.491	0.271	0.559	0.707	0.247	0.602	0.427

Source(s): Authors' Estimation, Table 4 by authors

Table 4.
Generalized Hurst exponents of after the GFC sample for short and long term components from −5 to 5

makes it easier for investors to predict the stock return and earn the abnormal profit (Tiwari *et al.*, 2017). A study by Hasan and Mohammad (2015) revealed that during the post-crisis era, a decline was observed in multifractality indices of all markets, with the exception of the Malaysian market. Another research by Anagnostidis *et al.* (2016) claimed that after GFC, anti-persistent behavior had been observed in Spain and France's stock price movements. Also, scholars observed improvement in the post-crisis period instead of the availability of significant mean-reverting patterns. In contrast, across the sample period, Germany, Netherlands, Greece and Italy were considered to be weak-form efficient.

The outcomes of the COVID-19 period are illustrated in Table 5. We identified that at $q = -5$, Belgium has the largest (q) value, the most persistent in the short and long run. Nevertheless, at $q = 2$ in the case of long-term fluctuation, most of the countries are showing long term persistency having $h(q) > 0.5$ except Austria, Belgium and Ireland, presenting short-term persistence in the long run. While France is showing short-term persistence in the short run as h(q) is less than 0.5, these countries' market returns will be negative in the future if it is currently positive. Hence, results confirm that in COVID-19 period, the stocks of Belgium and France are most fluctuating. The results are in line with the findings of Abuzayed *et al.* (2021) and Khattak *et al.* (2021). The prior studies also claim that in the times of COVID-19, Belgium, the UK and France are the most incremental systemic risk receivers. Hence, the stock markets are adversely exposed to the emergence of the deadly coronavirus. Due to COVID-19, the GDP of Belgium declined by 6.3% in 2020. The economic failure because of COVID-19 outbreak is the greatest yearly GDP decline ever observed in Belgium after Second World War. This is significantly larger than the drop observed during the GFC. At that time, GDP declined by a "mere" 2% in 2009 after having risen by 0.4% in 2008. Further, Sami and Abdallah (2021) claims that stock market returns are highly volatile. Also, as per the statistics, the most crucial stock of France, i.e. CAC 40, witnessed a fall of 37% from its highest value. In a nutshell, the stock markets of Belgium and France witnessed a downturn.

4.2.3 Ranking efficient markets. The next step in MF-DFA is to rank the efficient markets based on the market deficiency measure (MDM) score .

Table 6 illustrates country's rank based on the efficiency of the market both in the short run and in the long run. The most efficient market has an MDM value equal to zero, while the less efficient market has a higher MDM value (Mensi *et al.*, 2017). According to the MDM ranking, Portugal is the most efficient market, with the lowest MDM value (1.277), and Austria, with the highest MDM value (2.3838), is the most inefficient market in the short and long run. Austria is the most efficient market after having the lowest MDM value (0.5689), and Slovakia is the most inefficient market in the long run, with the highest MDM value (0.899).

According to the given output of MDM ranking before the GFC of 2007–2008, Greece is the most efficient market with the lowest MDM value (0.847) in the short run. On the other hand, Austria is the most efficient market in the long run after having the lowest MDM value (0.5499). In GFC, the Netherlands is the most efficient market having the lowest MDM value (0.744), and Ireland is the most efficient market in the long run based on MDM value (0.4452). Simultaneously, Austria and Slovakia are the most inefficient markets before and after GFC, both in the short and long run. In COVID-19, Finland is the most efficient market as MDM value is (1.3071) in the short run. The second most efficient is Germany (1.4245). Conversely, in long run, the most efficient market is Germany (0.5512) which is followed by Austria with an MDM value of (0.5783). However, in the short run, Belgium (4.4943) and France (2.8755) are appeared to be the least efficient. Likewise, the least efficiency is exhibited by Belgium (1.5974) in long run. Also, the results depict that the stock markets of Belgium and France are highly fluctuating, making markets inefficient in the short and long run. Finally, we suggest that the investors should invest in the markets with the lowest MDM value to earn abnormal profit as these stock returns are predictable.

Country	Austria		Belgium		Finland		France		Germany		Greece		Ireland	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	4.187	0.581	8.977	3.33	4.775	1.253	5.501	1.168	1.483	0.915	2.756	0.476	2.362	1.072
−4	4.111	0.463	8.791	3.218	4.673	1.189	5.398	1.136	1.491	0.911	2.707	0.493	2.351	1.069
−3	3.971	0.317	8.446	3.024	4.497	1.086	5.152	1.099	1.536	0.928	2.618	0.55	2.338	1.044
−2	3.698	0.163	7.701	2.684	4.138	0.92	4.465	1.059	1.686	0.989	2.404	0.74	2.314	0.97
−1	3.153	0.044	5.862	2.135	3.38	0.803	2.784	1.016	2.068	1.112	1.806	1.216	2.241	0.822
0	2.234	0.012	3.04	1.43	2.441	1.01	0.981	0.966	2.454	1.199	1.034	1.497	2.049	0.626
1	1.310	0.091	1.429	0.787	1.887	0.957	0.432	0.905	2.272	1.038	0.959	1.118	1.706	0.471
2	0.758	0.256	0.684	0.356	1.563	0.577	0.401	0.833	1.882	0.688	1.02	0.855	1.309	0.384
3	0.459	0.448	0.351	0.212	1.33	0.23	0.39	0.753	1.572	0.387	1.025	0.797	0.988	0.304
4	0.283	0.62	0.198	0.123	1.158	0.122	0.353	0.675	1.358	0.191	1.008	0.826	0.764	0.217
5	0.170	0.751	0.118	0.103	1.033	0.092	0.312	0.603	1.211	0.069	0.967	0.88	0.613	0.137

Country	Italy		Netherland		Portugal		Slovakia		Slovenia		Spain	
Order of q	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
−5	4.051	1.378	3.447	1.498	3.006	1.315	3.811	2.107	3.657	2.624	3.45	2.107
−4	3.904	1.347	3.351	1.457	2.912	1.289	3.68	2.055	3.536	2.62	3.32	2.055
−3	3.682	1.322	3.207	1.411	2.779	1.275	3.484	1.993	3.358	2.607	3.122	1.993
−2	3.332	1.321	2.978	1.37	2.6	1.296	3.2	1.934	3.107	2.574	2.805	1.934
−1	2.79	1.339	2.6	1.33	2.381	1.344	2.841	1.874	2.792	2.473	2.311	1.874
0	2.084	1.271	2.047	1.214	2.132	1.3	2.494	1.737	2.477	2.195	1.696	1.737
1	1.377	1.03	1.419	0.953	1.862	1.071	2.225	1.466	2.212	1.711	1.14	1.466
2	0.818	0.694	0.878	0.615	1.601	0.736	2.031	1.127	2.004	1.195	0.731	1.127
3	0.457	0.397	0.509	0.326	1.388	0.435	1.89	0.832	1.844	0.806	0.463	0.832
4	0.252	0.189	0.288	0.13	1.235	0.22	1.789	0.619	1.727	0.548	0.305	0.619
5	0.14	0.052	0.159	0.006	1.13	0.077	1.718	0.476	1.643	0.377	0.213	0.476

Source(s): Authors' Estimation, Table 5 by authors

Table 5.
Generalized Hurst exponents of during COVID-19 sample for short and long term components from −5 to 5

Ranking	Short-term Country	MDM	Ranking	Long-term Country	MDM
Full sample period					
1	Portugal	1.277	1	Austria	0.5689
2	Greece	1.306	2	Slovenia	0.710
3	France	1.4314	3	Germany	0.7399
4	Germany	1.4789	4	Spain	0.740
5	Netherland	1.624	5	Finland	0.7572
6	Ireland	1.6649	6	Italy	0.758
7	Italy	1.767	7	France	0.7668
8	Spain	1.820	8	Netherland	0.774
9	Belgium	1.8248	9	Portugal	0.778
10	Finland	1.8892	10	Belgium	0.792
11	Slovenia	1.962	11	Ireland	0.7924
12	Slovakia	2.114	12	Greece	0.7944
13	Austria	2.3838	13	Slovakia	0.899
Before the GFC					
1	Greece	0.847	1	Austria	0.5499
2	France	0.966	2	Slovenia	0.557
3	Slovakia	1.013	3	Ireland	0.6562
4	Italy	1.027	4	Belgium	0.6648
5	Germany	1.0845	5	Spain	0.667
6	Ireland	1.1195	6	Netherland	0.697
7	Belgium	1.1428	7	Greece	0.7042
8	Finland	1.1461	8	Germany	0.7399
9	Portugal	1.168	9	France	0.7812
10	Spain	1.186	10	Finland	0.786
11	Netherland	1.277	11	Portugal	0.798
12	Slovenia	1.399	12	Italy	0.807
13	Austria	1.7444	13	Slovakia	0.896
After the GFC					
1	Netherland	0.744	1	Ireland	0.4452
2	Portugal	1.018	2	Germany	0.5202
3	France	1.0369	3	Belgium	0.5366
4	Ireland	1.1264	4	France	0.5389
5	Germany	1.2372	5	Finland	0.55
6	Greece	1.2414	6	Slovenia	0.558
7	Finland	1.2926	7	Netherland	0.569
8	Belgium	1.4796	8	Italy	0.594
9	Italy	1.584	9	Austria	0.6345
10	Slovenia	1.622	10	Portugal	0.669
11	Spain	1.748	11	Spain	0.669
12	Slovakia	2.076	12	Greece	0.7222
13	Austria	2.1421	13	Slovakia	0.810
COVID-19 period					
1	Finland	1.3071	1	Germany	0.5512
2	Germany	1.4245	2	Austria	0.5783
3	Ireland	1.5578	3	Finland	0.6053
4	Spain	1.8123	4	Ireland	0.6429
5	Netherland	1.8193	5	Greece	0.6665
6	Greece	1.8539	6	Portugal	0.7545

Table 6.
MF-DFA rankings for short and long-term components

(*continued*)

Ranking	Short-term Country	MDM	Ranking	Long-term Country	MDM
7	Portugal	2.0736	7	Italy	0.768
8	Italy	2.0779	8	Netherland	0.7937
9	Austria	2.1968	9	France	0.9052
10	Slovenia	2.6314	10	Spain	1.3369
11	Slovakia	2.7348	11	Slovakia	1.3369
12	France	2.8755	12	Slovenia	1.5838
13	Belgium	4.4943	13	Belgium	1.5974

Source(s): Authors' Estimation, Table 6 by authors

Table 6.

5. Conclusion

This research explores asymmetric market efficiency of the 13 Euro countries concerning the period before GFC, after GFC and the period of COVID-19 by employing MF-DFA. Further, it aims to explore the efficiency of markets based on MDM scores. The findings suggest that efficiency in these markets varies over time. It implies that all markets possess multifractal properties. These markets are not deteriorating efficiently over time, and all markets reject the hypothesis of random walk behavior. Further, developed economies' market behavior is more toward stability, but emerging economies' behavior is less stable. This study's implication is for investors to earn abnormal profits and help predict the future returns of anti-persistent markets. It will assist these countries' economies in the implementation of relevant regulations on stock markets. It is crucial to have in-depth knowledge about stock indices, and in which particular sector the development of speculative bubbles is more likely to appear. Eurozone markets play a major role in crisis; hence, a comprehensive understanding of their behavior is necessary. More importantly, it is suggested that policymakers should start enforcing laws and legislation to improve the efficiency of these markets and strengthen local and international investors' confidence in them.

The results indicate that only two countries' markets show anti-persistent or negative autocorrelation behavior; after GFC, seven countries' markets exhibit anti-persistent autocorrelation. These markets' anti-persistent behavior provides ease to investors to predict the stock return and earn abnormal profit. Based on the MDM ranking, it is concluded that Portugal is the most attractive market and Austria is the least attractive market in terms of future return in the short run. However, Austria is the most favorable market for investors in the long run, and Slovakia is the least efficient market.

According to the results of the before-GFC period, Greece is the most favorable market, and again Austria is the least significant market for future returns in the short run. Whereas, in the long run, Austria is the most efficient market for investors in terms of their efficiency, and Slovakia is the least preferred market for investors before the GFC of 2007–2008. After GFC, the MDM ranking tells a different story, as the Netherlands is the most significant market in the short run, and Ireland is the most efficient in the long run from an investing point of view. However, Austria and Slovakia are still the least efficient markets in the short and long run, consistently before and after the financial crisis.

During the period of COVID-19, the discovered results are surprising and different from the full sample and GFC pre and post-periods. As per the outcomes of Generalized Hurst exponents during COVID-19 sample for short and long term components and market efficiency, the most fluctuating stocks are of Belgium and France in long and short run. Most importantly, Belgium's stock markets appear to be highly fluctuating, hence, making the market least efficient in short and long run. Moreover, France is also the second least efficient market in short run. Conversely, the most efficient market in the times of COVID-19 is Finland

and Germany in the short and long run, respectively. The reason for the sudden change in the results is the robust role of COVID-19.

These vibrant market conditions of 13 countries can be defined in bear markets, such as markets with low growth opportunities and bull markets having high growth opportunities, and regular markets with stable conditions. These market conditions are persistent. Our study results can divide these 13 countries into different segments, as we have incorporated the crucial role of the GFC and COVID-19 in the stock markets of 13 Eurozone countries. Countries showing long-term persistence can be viewed as regular markets or bull markets, and countries showing anti-persistent behavior can be viewed as bear markets. However, again, it also depends on the country's economic condition, and the occurrence of any black swan event that may alter the condition, such as an outbreak of coronavirus, has affected the global markets adversely. Although it started in China gradually, unfortunately, it has spread worldwide and upset the world economy.

6. Future recommendations

We recommend the scholars: (1) to conduct a comparative study by considering the data of different economies. For instance, comparison between China–USA, BRICS countries, developed-developing economies, European-Asian countries and Islamic countries. It will provide a novel idea of how different economies respond to GFC and COVID-19 with respect to EMH and MF-DFA. (2) We considered the overall stock markets of Eurozones; however, each market responds differently during crises like GFC and COVID-19. Hence, it is suggested to consider a specific stock market for in-depth analysis—for instance, the health, hospitality, tourism and telecommunication sectors.

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Multi-frequency information transmission among constituents and global equity returns: a sustainable and conventional way of investing

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Abstract

Purpose – This study investigates information flow of market constituents and global indices at multi-frequencies.

Design/methodology/approach – The study's findings were obtained using the Improved Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (I-CEEMDAN)-based cluster analysis executed for Rényi effective transfer entropy (RETE).

Findings – The authors find that significant negative information flows among sustainability equities (SEs) and conventional equities (CEs) at most multi-frequencies, which exacerbates diversification benefits. The information flows are mostly bi-directional, highlighting the importance of stock markets' constituents and their global indices in portfolio construction.

Research limitations/implications – The authors advocate that both SE and CE markets are mostly heterogeneous, revealing some levels of markets inefficiencies.

Originality/value – The empirical literature on CEs is replete with several dynamics, revealing their returns behaviour for diversification purposes, leaving very little to know about the returns behaviour of SE. Wherein, an avalanche of several initiatives on Corporate Social Responsibility (CSR) enjoin firms to operate socially responsible, but investors need to have a clear reason to remain sustainable into the foreseeable future period. Accordingly, the humble desire of investors is the formation of a well-diversified portfolio and would highly demand stocks to the extent that they form a reliable portfolio, especially, amid SEs and/or CEs.

Keywords Entropy, Mutual information, Decomposition, Sustainable responsible investing, Frequency-dependent

Paper type Research paper

1. Introduction

The idea and tenets of SRI have gained prominence and have taken over new investors' management funds around the world (Townsend, 2020). Socially Responsible Investing (SRI)

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portfolios typically exceed or generate returns that are at least comparable to market performance from the standpoint of portfolio management (Berkman *et al.*, 2021). For instance, evidence indicates that when additional financial grades are used as proxies for a firm's CSR behaviour, a strategy in which investors buy the most socially responsible corporations and sell the least socially responsible companies yields positive alphas (Lins *et al.*, 2017). By doing both good and well, socially conscious investors can maximise their returns.

As opposed to using CSR ratings and business performance indicators, the construction of a market-based framework that provides a sound legal and regulatory environment has recently received priority (Levine, 2005). This is supported by the increase in financial markets' integration due to the heightened financial openness and trade liberalisation policies across the globe while ensuring richer risk management mechanisms and the forming of reliable portfolios. Therefore, the market-based system promotes economic development in the long run through the synergistic impact of a broad array of firms (Balcilar *et al.*, 2018; Asafo-Adjei *et al.*, 2021a, b). This is particularly crucial since the numerous market performance contributions made by distinct CSR-inclined firms may combine to benefit blocs at the national, regional or international levels.

As a result, nascent and fledgling bodies of literature have shown that using equity and CSR measurements is responsive (Galema *et al.*, 2008; Hayward, 2018; Dorfleitner *et al.*, 2018; Durand *et al.*, 2019; Berkman *et al.*, 2021, etc.). The results of these research showed that SRI screening greatly outperforms the numeric (Derwall *et al.*, 2005). On the other hand, Geczy *et al.* (2021) found that investors are forced to pay a premium for the funds committed to SRI stock. However, Berkman *et al.* (2021) found no statistically significant difference between the 2008 Global Financial Crisis (GFC) performances of high and low CSR-inclined enterprises, adding to the varied dynamics of sustainability equity (SE) returns across time.

Nonetheless, it is not overwhelming to advocate that the upsurge in the share of SRI funds plays a significant role in ushering inducements towards an incessant elevation of SR standards to a degree that their performance is not steadily inferior to other funds (Consolandi *et al.*, 2009). This is a result of the topical diffusion of SRI equities to provide fresh intuitions into the SR standards on corporate equity's performance.

In order to combine global reach with local knowledge, the study uses the Standard & Poor's (S&P) Dow Jones sustainability equity indices, which debuted in 1999. Through collaboration with exchanges throughout the world, these indices were created for both the domestic and global investment communities (Naqvi and Jus, 2019a). The sustainability indices include, but are not limited to the World Index, the USA, North America, Emerging, Europe, Frontier and Sharia, covering a broad array of global and regional blocs.

The Dow Jones Sustainability Index (DJSI) has a tremendous market influence and a promising future for the sustainability investing sector (Naqvi and Jus, 2019b; Townsend, 2020). Over 37,000 sustainable indicators were accessible globally as of 2019 (Naqvi and Jus, 2019a). Some initiatives, including the United Nations (UN) Sustainable Development Goals in 2015, which urge most businesses worldwide to have a crucial mandate to operate sustainably, help to support this (Naqvi and Jus, 2019a).

The DJSI World as a possible proxy for the global sustainability index is made up of premier environmental performers regarding a benchmark of the 1st 10% of industry performers (Fundamental Rights Report, 2016; Durand *et al.*, 2019). This induces competition for firms keen to be included, continued or expunged from the index. Accordingly, the strength of information flows among the markets of similar or differing asset classes are intensified by irrational investors' persistent search for competing risks and returns to meet their portfolio goals to accentuate the competitive market hypothesis (CMH) of Owusu Junior *et al.* (2021b).

Despite the expanding corpus of literature on SEs, there is still a lack of knowledge addressing the structure of returns from sustainable investments and information flows

across different investment horizons (Consolandi *et al.*, 2009; Hawn *et al.*, 2018; Hayward, 2018; Durand *et al.*, 2019; Helliar *et al.*, 2022). As a result, the study examines the return behaviour of sustainability-related stocks in relation to the degree of information flow across the stocks across investment horizons. This is important to consider when evaluating risk management choices, portfolio diversification and the distribution of government rules and policy decisions regarding sustainable equities.

Existing literature has not yet utilised multi-frequency techniques to respond to information flow among SEs amid conventional equities (CEs). The techniques are the Improved Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (I-CEEMDAN)-based cluster analysis and entropy. Although a plethora of literature has utilised most of these techniques on several other financial assets (Zhu *et al.*, 2015; Adam *et al.*, 2022; Owusu Junior *et al.*, 2021b; Gyamfi *et al.*, 2021; Asafo-Adjei *et al.*, 2022a etc.), limited attention has been extended to SE returns.

The I-CEEMDAN is a viable approach for sampling, dealing with signal noise and greatly reducing the frequency aliasing problem that can arise with EMD, EEMD and CEEMDAN, as respectively proposed by Huang *et al.* (1998), Wu and Huang (2009) and Torres *et al.* (2011). The I-CEEMDAN decomposes input signals into main modes. The modes are termed as intrinsic mode functions (IMFs). The IMFs depict – short-, medium- and long-term horizons which are considered in this current study to respond to information flow.

Additionally, the transfer entropy measures the reduction in uncertainty, particularly, when forecasting variables are conditioned on past values and thus makes it easier to model statistical causality between financial time series (Adam, 2020; Benthall, 2019). To account for tail events which are ideal for revealing stressed markets outcomes (Asafo-Adjei *et al.*, 2022a), the Rényi transfer entropy is applied in this study.

The employed methodologies help to capture multi-frequency information flow between equity returns better for investing decisions. For instance, it would enable investors to observe the degree of extensive propagation of shocks among assets at various investment horizons (short, medium and long terms) where the knowledge of one asset, possibly, indicates considerably more uncertainty than knowing the history of only the other asset. Accordingly, investors are able to minimise their portfolio risks and earn better returns at certain investment horizons depicted at by the multi-frequencies coupled with a negative information transfer (Boateng *et al.*, 2022; Bossman *et al.*, 2022a). This is in response of the heterogeneous, competitive and adaptive behaviours of markets in line with the behavioural market hypothesis where markets' participants are irrational across investment horizons, which makes them state-dependent.

We contribute to the literature in the following ways. First, we form a portfolio among sustainable equities amid CEs. Second, the I-CEEMDAN-based cluster analysis is utilised in this study to effectively reduce noise from the data and form a reconstructed series of high , medium and low frequencies in addition to the residue. This approach is relevant to capturing information at diverse investment horizons while maintaining, to a large extent, the delayed responses of prices to information relative to the individual IMFs, which might not provide sufficient returns behaviour. Accordingly, in this study, we combine similar IMFs by observing the mean periods of the equity returns obtained through cluster analysis. Third, we investigate information flows among SEs amid CEs with the aid of the Rényi transfer entropy, which allows enquiries of financial time series at low probability events. Low probability events are mostly preferred by assigning higher weights to the lower tails since most financial time series are prone to dropdowns.

The remaining sections are arranged in the following ways. We present the methodology required to achieve the purpose of this study in section 2. Section 3 has the results and discussion of the study whereas section 4 concludes the study.

2. Literature review

Information flow is defined by diverse academic disciplines; however, most definitions of information flows in the natural sciences are built on the foundational work of Shannon (1948) with several other applications, including physics (Edet and Ikot, 2021; Jaynes, 1957; etc.), biology (Mikhailovsky, 2021; Skinner and Dunkel, 2021) and finance (Asafo-Adjei *et al.*, 2022a; Bossman *et al.*, 2022a; Adam, 2020; Agyei *et al.*, 2022d; Asafo-Adjei *et al.*, 2022e; Boateng *et al.*, 2022; Bossman *et al.*, 2022b; Qabhobho *et al.*, 2022; etc.). Information is transmitted among entities in two ways: first, a classification by abstract states and second, the degree of background linkages and regularities the entities share (Ostalé, 2020). Regularity is the state of being predictable to enhance effective decision-making. As posited by Ostalé (2020), it is not necessary to determine what the entities are, so long as they relate to each other using a classificatory relation, information flows become prominent. Moreover, Benthall (2019) avers that information flows are located in the context of causal linkages. It becomes obvious to indicate that information flow theory makes it possible to quantify the extent to which one thing carries information about another.

Outcomes provided by empirical studies divulge that reciprocal information exists owing to interconnections between variables and that one variable can learn from the behaviour of the other through observation. Information flows among variables become reliable when the information is well refined, due to surges in the number of connections (Ostalé, 2020). This can be applied in financial time series which experience rapid oscillations. As a result, decomposition-based information flows become a suitable tool to ensure a more refined noise reduction information flows between financial assets. A growing body of academic literature in finance and economics employs information flow theories due to several reasons, including the degree of similarities, integration and competitiveness occasioned by the irrational behaviour of investors across investment horizons. It becomes necessary to examine information flows among SEs that demonstrate high market performance with prospects for similar dynamics.

The current study also sheds light on the CMH of Owusu Owusu Junior *et al.* (2021b) that "in part, the intensity of information flows and spillover between markets of the same and differing asset classes are exacerbated by rational, albeit irrational investors' relentless search of competing rewards and risks to satisfy the portfolio goals" (p. 2). Consequently, there is a high expectation of information flows among SEs across diverse investment horizons (short, medium and long term) and calendar times regarding market participants' irrationality. It is blatant that the behavioural dynamics of financial markets stimulate asymmetry, nonstationary and nonlinearity escalating noise in asset returns' price-generating systems requiring a pragmatic approach to account for these complexities.

A growing body of academic literature has spearheaded the exploration of information transmissions between financial assets through the information theory. Information is transmitted among financial assets classes regarding competing risks and returns intensified by the behavioural intentions of investors across investment horizons. This has made most financial asset classes exhibit mutual information where most of these assets can observe the behaviour of others. The empirical literature on information flows is replete with information flows among financial assets such as commodities (Lahmiri and Bekiros, 2020b; Asafo-Adjei *et al.*, 2022a, b) global, regional and major world markets (Lahmiri and Bekiros, 2020a; Owusu Junior *et al.*, 2021a; Asafo-Adjei *et al.*, 2021c; Bossman, 2021; Bossman *et al.*, 2022a), cryptocurrencies (Jang *et al.*, 2019; Asafo-Adjei *et al.*, 2021c; Assaf *et al.*, 2022), etc. Findings from these studies are inconclusive and may be subjected to different structural breaks or sampled period analyses revealing diverse economic events for distinct assets classes.

Outcomes from these studies either indicate asymmetric or nonlinear bi-directional and unidirectional causality among financial assets (Jang *et al.*, 2019; Owusu Junior *et al.*, 2021b; Asafo-Adjei *et al.*, 2021c; Assaf *et al.*, 2022; Bossman *et al.*, 2022a, etc.) or reveal less significant information flows (Bossman, 2021; Asafo-Adjei *et al.*, 2022a, b; etc.). Notwithstanding,

depending on the direction of causality and the market conditions, diversification, safe haven and hedging benefits become predominant for certain asset classes. Moreover, it must be noted that outcomes from these studies mostly divulge the concentration of randomness and disorder in less probable events. What is yet to be known is information flow between sustainable and conventional equities at diverse investment horizons.

It becomes arguable whether SEs emulate similar dynamics of these conventional equities at diverse investment horizons. There exist countless SEs at the individual firm, national and global levels. However, due to the increasing level of financial and economic integration among most financial assets, the study employs regional as well as global proxies of the sustainable and conventional equities to better capture the multi-frequency information flow.

As averred by Kwon and Yang (2008) and Osei and Adam (2020), information flows between stock markets occur between the entire market and its constituents as well as other financial markets. This is not overwhelming because stock markets operate in a nonisolated system, which interacts and exchanges information with the real economy. That is, individual stocks are priced depending on several factors but are not limited to available information to the entire market, information peculiar to the individual stocks as well as information from other financial assets (Osei and Adam, 2020). As a result, the study examines information flows between regional equities as constituents and global equities as the entire market. To effectively bridge the gap in prior literature on information flows, the study does not only consider information flows among the SEs but includes other conventional assets to enhance comparison.

3. Methodology

3.1 I-CEEMDAN

The I-CEEMDAN proposed by Colominas *et al.* (2014) has the best of these qualities when compared to the others. While CEEMDAN performs better than previous methods in removing noise, reconstructing the signal and determining SNR, it falls short on two counts: (1) residue noise is contained in the model and (2) spurious mode issue (Li *et al.*, 2020). The I-CEEMDAN algorithm adapted from Li *et al.* (2020) is as shown as follows.

(1) Append a white-noise $\tau_1[\omega^{(i)}]$ to a signal x to result in a new series

$$x^{(i)} = x + \rho_0\left(\omega^{(i)}\right), i = 1, 2, \ldots, N, \tag{1}$$

where $\omega^{(i)}$, ρ_0 and N are the i-th white noise added, SNR, and several white noise appended respectively.

(2) Compute the local mean of $x^{(i)}$ using EMD and retrieving the first residual

$$r_1 = \left(\frac{1}{N}\right)\sum_{i=1}^{N} M\left(x^{(i)}\right), \tag{2}$$

from which first IMF $c_1 = x - r_1$ can be obtained.

(3) Recursively obtain the k-th IMF $c_k = r_{k-1} - r_k$, for $k \geq 2$, where

$$r_k = \left(\frac{1}{N}\right)\sum_{i=1}^{N} M\left(r_{k-1} + \rho_{k-1}\tau_k\left(\omega^{(i)}\right)\right) \tag{3}$$

3.2 Cluster analysis

The IMFs were classified in this work into multi-frequencies (high, medium and low frequencies) using the Cluster analysis technique. The multi-frequencies were discovered by

looking at the mean periods of each IMF (Zhu *et al.*, 2015; Gyamfi *et al.*, 2021; Adam *et al.*, 2022; Asafo-Adjei *et al.*, 2022a). In this instance, the mean period was calculated using the average frequency of each IMF. According to Adam *et al.* (2022), it is determined by dividing the total number of points by the total number of peaks.

$$\frac{Total\ observations}{number\ of\ maxima} \tag{4}$$

where the extrema function is used to determine the number of maxima (peaks). Utilising knowledge from the dynamics of the mean periods, the IMFs are combined to create a rebuilt series into each of their individual multi-frequencies.

3.3 Rényi effective transfer entropy (RETE)

The Rényi transfer entropy (RTE) (1970), which indicates uncertainty inside a system, is built on the Shannon entropy (Shannon, 1948; Behrendt *et al.*, 2019). Due to the research of a probability distribution, several experiments (p_j) are carried out. According to Hartley (1928), if the average information is found, symbols take the following form:

$$H = \sum_{j=1}^{n} P_j log_2\left(\frac{1}{P_j}\right) \text{bits}\,, \tag{5}$$

where n denotes several symbols' observations regarding probabilities P_j.

The Shannon entropy shows a discrete random variable (J). According to Behrendt *et al.* (2019), the typical number of bits required for encoding independent draws at the maximum can be represented as follows:

$$H_J = -\sum_{j=1}^{n} P(j) log_2 P(j) \tag{6}$$

Under the Markov framework, Shannon entropy took insights from the Kullback–Leibler distance concept to measure information flows amid two time series. The study considers two discrete random variables, I and J (which are the equity indices), and corresponding marginal probabilities of $P(i)$ and $P(j)$. Simply, the joint probability of the discrete variables can be seen as $P(i,j)$. It has a dynamic structure that resembles a stationary Markov process of order k (Process I) and I (process J). The Markov property implies that the probability of spotting I at time $t+1$ in state i dependent on the k prior observations is $p(i_{t+1}|i_t,\ldots,i_{t-k+1}) = p(i_{t+1}|i_t,\ldots,i_{t-k})$. In encoding the observation in $t+1$, the mean number of bits needed, given that the *ex ante* k observations are obtained, can be offered in the following form:

$$h_j(k) = -\sum_{i} P\left(i_{t+1}, i_t^{(k)}\right) log P\left(i_{t+1}|i_t^{(k)}\right) \tag{7}$$

where $i_t^{(k)} = (i_t,\ldots,i_{t-k+1})$ (for process J). Under the Kullback–Leibler distance phenomenon in the context of two random variables, the flow of information from process J to process I is estimated through quantification of the deviation from the generalized Markov property $P(i_{t+1}|i_t^{(k)}) = P(i_{t+1}|i_t^{(k)}, j_t^{(I)})$. Regarding what is presented earlier, the Shannon entropy is then shown as follows:

$$T_{J\to I}(k,l) = \sum P\left(i_{t+1}, i_t^{(k)}, j_t^{(l)}\right) log \frac{P\left(i_{t+1}|i_t^{(k)}, j_t^{(I)}\right)}{P\left(i_{t+1}|i_t^{(k)}\right)} \tag{8}$$

where $T_{J\to I}$ estimates information flows from J to I. Harmoniously, information flows $T_{I\to J}$ can be realised as from I to J. Quantifying the differential can disclose the prevailing direction of the information flow between $T_{J\to I}$ and $T_{I\to J}$.

Following Beck and Schögl (1995), the escort distribution $\varnothing_q(j) = \frac{p^q(j)}{\sum_j p^q(j)}$ with $q > 0$ to normalise the weighted distributions is applied to emphasise the resultant RTE as

$$RT_{J\to I}(k,l) = \frac{1}{1-q} P\left(i_{t+1}, i_t^{(k)}, j_t^{(I)}\right) log \frac{\sum_i \varnothing_q\left(i_t^{(k)}\right) P^q\left(i_{t+1} | i_t^{(k)}\right)}{\sum_{i,j} \varnothing_q\left(i_t^{(k)}, j_t^{(I)}\right) P^q\left(i_{t+1} | i_t^{(k)}, j_t^{(I)}\right)} \tag{9}$$

It should be noted that the RTE computation can reveal reversed results. As a result, knowing J record creates noticeably more doubt than knowing I record alone would. For possible diversification, this is perfect. The effective transfer entropy is determined as the transfer entropy divided by the effective sample size because the transfer entropies may be skewed in small samples (Marschinski and Kantz, 2002), as shown in equation 10:

$$ETE_{J\to I}(k,l) = T_{J\to I}(k,l) - T_{Jshuffled\to I}(k,l), \tag{10}$$

where $T_{Jshuffled\to I}(k,l)$ represents the transfer entropy using a shuffled version of the time series J; that is, through a random selection of observations from the actual time series J and adjusting them to produce a fresh time series, causing chaos for the dependencies in time series J, but not superintending the statistical reliance between J and I. Recurrent RTE estimations are used to determine the information transmission, which has a null hypothesis that there are no information flows.

3.4 Data sources and description

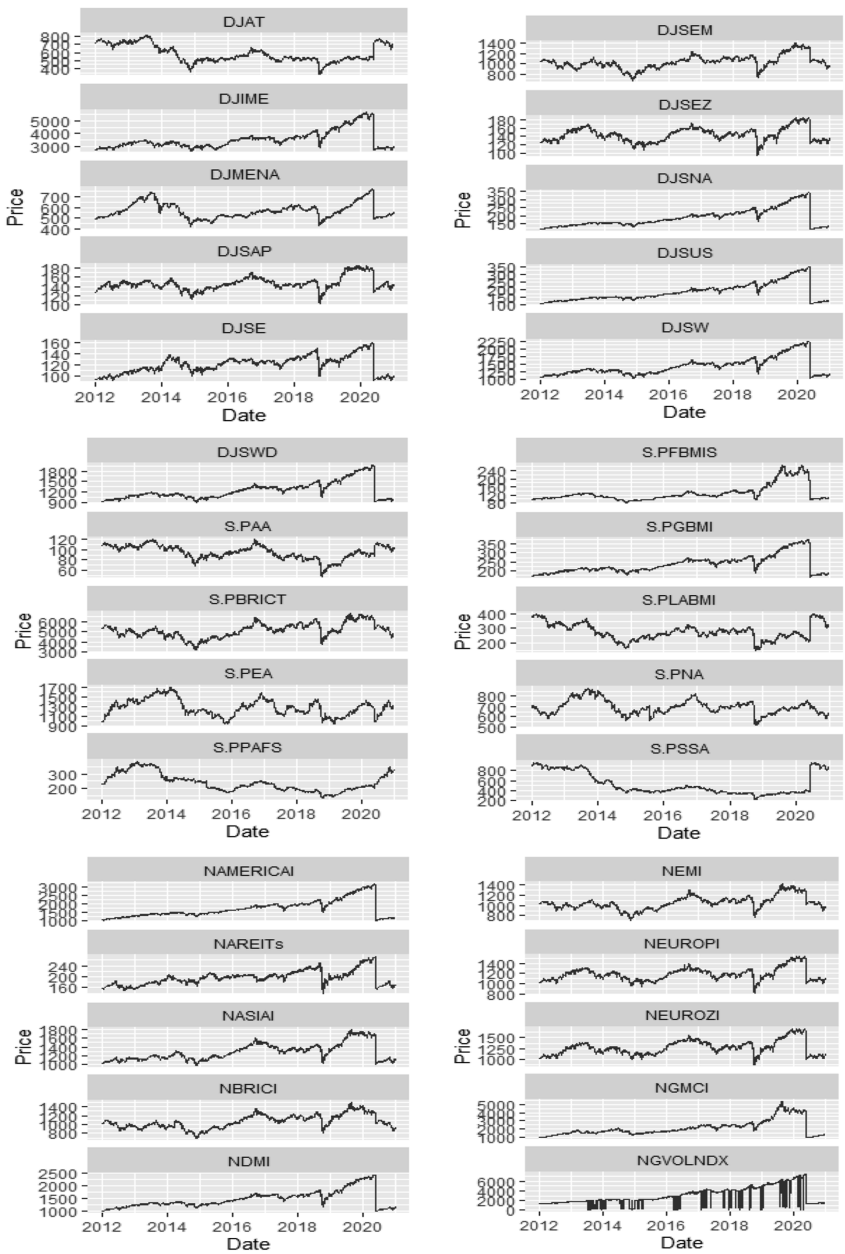
Daily S&P Dow Jones sustainability equity indices from Global, Africa, Asia, North America, South America, Emerging, Europe, Frontier, Shariah and other regional categories were used in the research. As a result of the increased financial market integration and capital market liberalisation within regional blocs, the study uses global and regional categorisations of sustainability equity indices (Owusu Junior *et al.*, 2021a). Asafo-Adjei *et al.* (2022b, c) further revealed high degree of similarities and integration among the selected sustainability equites due to the current trends in globalisation through liberalisation policies for a more integrated financial market. The daily S&P Dow Jones sustainability equity indices were gleaned from the RobecoSAM website.

To make comparisons easier, 10 conventional stocks are also included. Except for the NAREIT Global Real Estate Index and NASDAQ 100 Volatility Target (Global Indices), which were gleaned from yahoo finance and investing.com, respectively, the remaining indices were obatined from EquityRt. The daily data cover the period from November 12, 2012, to December 2, 2021, totalling 2,102 observations. The suggested time frame takes into account major economic events such as the aftermath of the 2008 GFC, the Eurozone crisis, trade tensions between the USA and China, the COVID-19 pandemic and so on. The sampled sustainability equity indices and conventional equities, which were chosen based on consistent data availability over the given period, are specifically shown as supplementary files (see, Table S1).

4. Results and discussion

4.1 Descriptive statistics

Figure 1 displays the prices of both sustainability and conventional equities from 2012 to 2021. It can be observed that the prices of SEs and CEs demonstrate similar dynamics across



Source(s): Figure by authors

Figure 1.
Plots of price series

time. Specifically, we notice a price dip for most equities in the first quarter of 2021. This suggests the delayed responsiveness of the equities prices to shocks from the COVID-19 pandemic. We notice an interesting outcome of a plunge in prices around 2019 for almost all

equities. During this period, investors fretted about a plummeting global economy. To mention a few, investors' worries emanated from disruptive trade wars, especially, the USA–China trade wars, excessive tariffs, Brexit (United Kingdom's desire to depart from the European Union), etc. This induced the IMF to downgrade its projections for global economic growth to approximately 3%, and considered the lowest estimate since the 2008 GFC.

Figure 2 presents logarithmic returns series for 20 SE returns and CE returns. As clearly shown in Figure 4, shocks in the return series are generally prominent in the early portions of 2020, suggesting the adverse impact of the COVID-19 pandemic. This highlights that SEs are not entirely insulated from severe economic shocks. The NGVOLNDX equity index on the other hand reveals chunks of excess fluctuations across time, demonstrating its relevance as a volatility measure. A glance at the DJSEZ index stipulates that the Eurozone crisis as a local regional economic shock has less impact on their average sustainability equity returns (ER) relative to the economic impact of the COVID-19 pandemic.

Seven descriptive statistics for 30 ER are shown in Table 1. Table 1 shows that ER have a poor performance and vary from −0.04% to 0.08%. All of the returned series have little variance, indicating some degree of regularity, with the exception of NGVOLNDX, whose spread is closer to 1. However, the data's distribution deviates from a normal distribution. This conclusion is quantitatively supported by the Jarque-Bera statistic for a nonnormal data distribution, which highlights negatively skewed and peaked distributions. Additionally, all of the return series are stationary according to the Kwatkowski–Phillips–Schmidt–Shin (KPSS) test, which demonstrates that the stationarity of all return series cannot be ruled out (p-value > 0.05). The initial returns series, however, appear to be nonlinear according to the Teraesvirta's neural network (TRS).

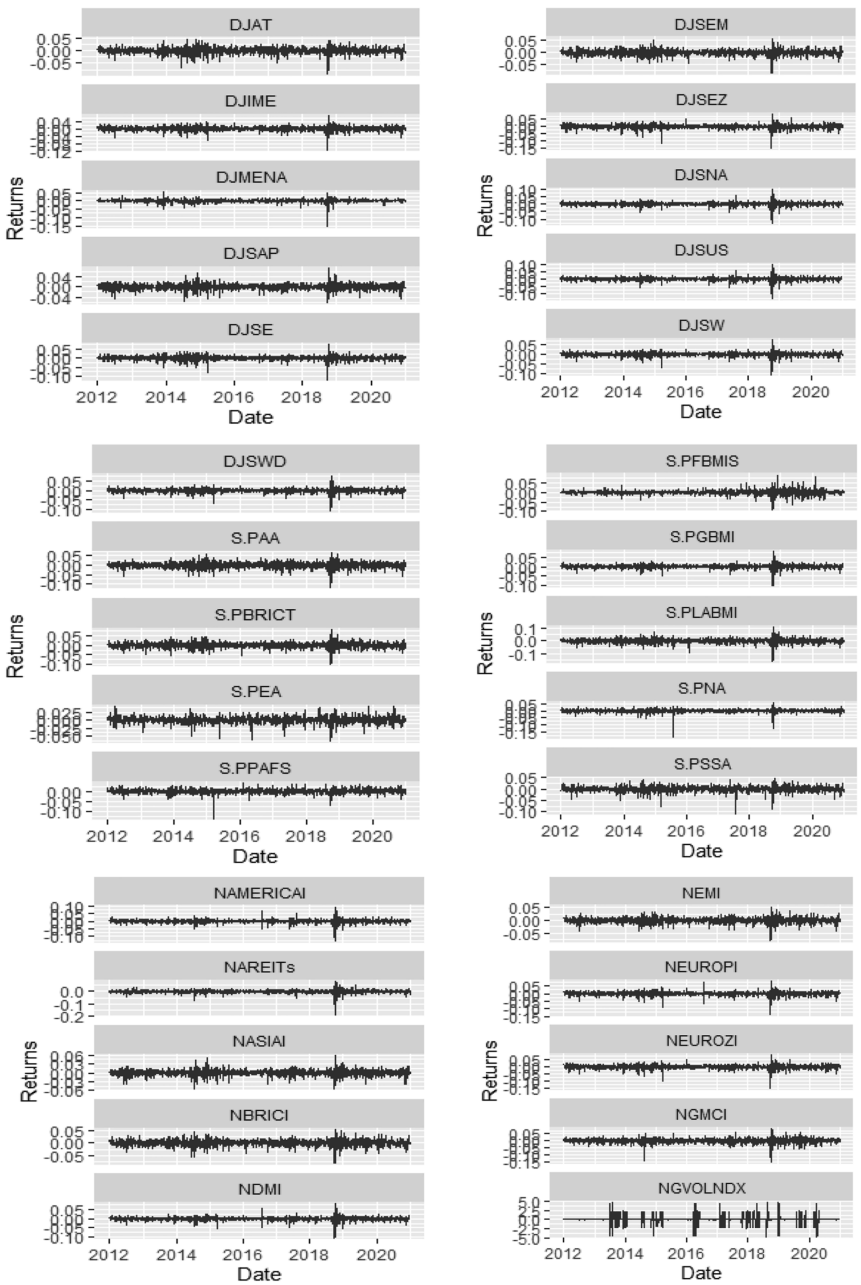
4.2 Procedures for IMF reconstruction into their multi-frequencies

Following the research of Asafo-Adjei *et al.* (2022b), the analysis employs 10 IMFs and a residue created using the I-CEEMDAN decomposition method for both sustainability and conventional ER. The properties of the mean period, Pearson product–moment correlation and variances are used to group the data into a variety of frequencies.

To support the reconstruction of the IMFs into many frequencies, the computations are displayed as supplemental files. With this method, the data's inherent complexity can be carefully examined in order to classify each IMF into its corresponding high, medium and low frequencies as well as the residual. The mean periods for the multi-frequencies for all variables are as follows: "(1) less than 30 days within less than 50 consecutive days from IMF1 to IMF4 (HFQ); (2) between 30–300 days within less than 3 consecutive years on 250 cumulative trading days from IMF1 and (3) more than 300 days whose sum from IMF1 is over 3 consecutive years but less than 7 years on an approximation of 250 trading days (LFQ)" (Asafo-Adjei *et al.*, 2022b, p. 12–13).

The residue, on the other hand, covers more than 7 years and 250 trade days. This is significant because it may be necessary to allocate adequate time periods to allow for a thorough evaluation of the nexus due to the delayed influence of price responses to information. Furthermore, the sample duration of this study allows for additional options besides solely depending on the information provided by existent literature, which may not always account for the simultaneous diverse dynamics of each IMF for each sampled set of data.

Table 2 presents two stationarity tests to examine whether or not the statistical properties of the ER vary with time. The augmented Dickey–Fuller (ADF) and KPSS tests are utilised in this study. The null hypothesis for the ADF test takes on a nonstationary series whereas the KPSS test suggests a stationary series. The tests are computed for all the multi-frequencies for each ER at the 1 and 5% significance levels.



Source(s): Figure by authors

Figure 2.
Returns series

Table 2 provides reasonable evidence to conclude that almost all the equity returns are stationary at the high and medium frequencies. Strictly for the KPSS test, all the equity returns for the low frequency and residue are not stationary (*p-value* < 0.01). Although the

ER	Mean	SD	SKW	KTS	JB	KPSS	TRS
DJAT	−0.0002	0.01	−1.09	10.44	5269.36**	0.06	6.70*
DJIME	0.0003	0.01	−1.11	15.07	13196.42**	0.07	12.92**
DJMENA	0.0002	0.01	−4.00	70.26	401789.60**	0.14	50.32**
DJSAP	0.0001	0.01	−0.20	8.12	2311.88**	0.04	7.54*
DJSE	0.0002	0.01	−1.26	16.09	15572.37**	0.03	14.85**
DJSEM	0.0001	0.01	−0.73	9.75	4171.62**	0.08	25.11**
DJSEZ	0.0002	0.01	−1.46	19.70	25167.70**	0.04	9.45**
DJSNA	0.0005	0.01	−1.05	26.35	48123.20**	0.06	101.88**
DJSUS	0.0005	0.01	−0.99	25.01	42787.88**	0.05	96.95**
DJSW	0.0003	0.01	−1.42	21.19	29678.92**	0.07	45.83**
DJSWD	0.0003	0.01	−1.39	21.28	29948.29**	0.06	46.32**
S.PAA	−0.0001	0.01	−0.79	9.12	3493.25**	0.04	6.34*
S.PBRICT	0.0001	0.01	−0.74	9.83	4278.79**	0.19	37.44**
S.PEA	0.0001	0.01	−0.74	9.31	3674.49**	0.07	0.80
S.PFBMIS	0.0003	0.01	−0.47	15.57	13919.09**	0.16	13.12**
S.PGBMI	0.0004	0.01	−1.58	24.72	42181.89**	0.11	54.10**
S.PLABMI	−0.0003	0.02	−1.17	15.59	14349.77**	0.05	81.01**
S.PNA	0.0000	0.01	−4.98	83.15	571353.00**	0.05	20.63**
S.PPAFS	−0.0001	0.01	−1.46	21.28	30017.39**	0.03	4.33
S.PSSA	−0.0004	0.01	−1.27	13.14	9560.10**	0.20	1.95
NAMERICAI	0.0005	0.01	−1.13	24.44	40723.38**	0.06	93.24**
NAREITs	0.0003	0.01	−2.37	41.74	133424.90**	0.03	27.88**
NASIAI	0.0002	0.01	−0.40	7.81	2083.30**	0.03	5.19
NBRICI	0.0001	0.01	−0.72	8.77	3099.72**	0.05	25.03**
NDMI	0.0004	0.01	−1.40	24.13	39801.01**	0.05	61.23**
NEMI	0.0001	0.01	−0.80	10.28	4867.94**	0.06	25.09**
NEUROPI	0.0002	0.01	−1.46	21.41	30425.21**	0.04	0.06
NEUROZI	0.0002	0.01	−1.50	19.81	25543.58**	0.04	7.08*
NGMCI	0.0007	0.02	−1.17	13.51	10147.28**	0.06	43.28**
NGVOLNDX	0.0008	0.75	−0.05	19.54	23967.01**	0.01	83.88**

Note(s): The mean values are specifically kept in four decimal points due to zero redundancy. [*; **] show significance levels at 5 and 1% respectively. SD, SKW, KTS, JB, KPSS and TRS, respectively, denote standard deviation, skewness, kurtosis, Jarque-Bera, Kwiatkowski–Phillips–Schmidt–Shin and Teraesvirta's neural network tests

Source(s): Table by authors

Table 1.
Descriptive statistics of equity returns

original series appears to be stationary which the test could not detect otherwise, it is the long-term trend and low frequency that vary with time. Accordingly, the dominant frequencies which are HFQ and MFQ drive the stationary series of the equities' original returns series. In this regard, the study concludes that stationarity is frequency-dependent.

Since financial time series are influenced by nonlinearity, the current study employs the TRS test which has linearity in the mean as the null hypothesis. In the TRS test, Taylor series expansion of the activation function is utilised to reach a fit test statistic (Teräsvirta, 1996; Zhang and Wang, 2011; Owusu Junior *et al.*, 2022). The TRS test is presented for HFQ, MFQ, LFQ and RESID for all the ER as shown in Table 3.

4.3 Information flows at multi-frequencies

We present an analysis of 20 sustainability and 10 conventional equity returns through the multi-frequency-based entropy approach at 95% confidence bounds. Specifically, the application of the multi-frequencies shows the relevance of multi-scales in financial time series in addressing the heterogeneous and adaptive dynamics of markets.

Equities	ADF				KPSS			
	HFQ	MFQ	LFQ	RESID	HFQ	MFQ	LFQ	RESID
DJAT	−17.70**	−8.15**	−6.60**	−17.83**	0.05	0.33	1.82**	20.48**
DJIME	−18.68**	−8.59**	−4.40**	−4.15**	0.07	0.02	0.94**	13.54**
DJMENA	−18.04**	−8.44**	−1.54	−23.16**	0.02	0.09	0.93**	5.92**
DJSAP	−16.78**	−8.47**	−0.84	−0.07**	0.02	0.25	2.28**	23.65**
DJSE	−16.90**	−9.92**	−1.21	−11.50**	0.03	0.03	1.33**	21.58**
DJSEM	−16.69**	−7.89**	−8.96**	1.02	0.04	0.05	1.85**	23.64**
DJSEZ	−18.90**	−7.84**	−6.46**	−6.83**	0.08	0.60*	2.33**	23.67**
DJSNA	−19.19**	−10.19**	−2.79	−1.49	0.06	0.04	1.17**	11.46**
DJSUS	−19.03**	−9.55**	−1.33	−26.35**	0.07	0.02	1.01**	12.98**
DJSW	−18.40**	−10.35**	−2.49	−6.25**	0.03	0.03	1.05**	13.29**
DJSWD	−18.22**	−8.78**	−0.58	−9.41**	0.02	0.02	0.94**	23.50**
S.PAA	−18.44**	−8.83**	−2.71	−28.39**	0.01	0.04	2.81**	15.45**
S.PBRICT	−16.94**	−7.65**	−5.94**	−2.85	0.13	0.17	4.84**	23.60**
S.PEA	−17.18**	−7.24**	−1.75	−9.76**	0.02	0.18	2.14**	23.65**
S.PFBMIS	−17.95**	−6.04**	−2.15	0.49	0.01	0.49*	4.32**	23.63**
S.PGBMI	−18.07**	−10.88**	−0.95	−12.88**	0.01	0.04	0.92**	19.22**
S.PLABMI	−17.59**	−7.96**	−1.00	−0.15	0.06	0.08	2.71**	23.63**
S.PNA	−16.40**	−7.46**	−1.68	−0.15	0.01	0.08**	0.84**	23.70**
S.PPAFS	−16.15**	−7.17**	−7.82**	−17.80**	0.08	0.21	1.75**	9.96**
S.PSSA	−17.87**	−8.99**	−2.46	−6.84**	0.04	0.03	2.34**	22.26**
NAMERICAI	−19.25**	−10.23**	−1.02	−25.66**	0.04	10.02	1.92**	6.84**
NAREITs	−16.58**	−8.95**	0.84	−3.18	0.03	0.04	3.10**	23.58**
NASIAI	−17.17**	−8.80**	−13.16**	0.38	0.02	0.06	5.35**	23.65**
NBRICI	−16.79**	−7.20**	−1.25	0.70	0.10	0.04	1.19**	23.65**
NDMI	−17.18**	−6.72**	−2.04	−0.09	0.02	0.04	3.69**	23.65**
NEMI	−17.44**	−7.77**	−0.98	−9.27**	0.07	0.08	2.95**	21.35**
NEUROPI	−17.16**	−8.31**	2.65	2.23	0.02	0.20	1.66**	22.97**
NEUROZI	−17.60**	−8.99**	−1.17	−22.51**	0.10	0.13	1.46**	4.95**
NGMCI	−18.01**	−9.07**	−7.27**	−1.85	0.01	0.10	2.43**	23.62**
NGVOLNDX	−12.46**	−10.28**	−2.61	10.17	0.09	0.59*	1.59**	22.45**

Table 2. Stationarity tests of equity returns

Note(s): [*, **] show significance levels at respectively 5 and 1%. HFQ, MFQ, LFQ and RESID denote high frequency, medium frequency, low frequency and residue, respectively
Source(s): Table by authors

To provide a smooth interpretation of the outcomes, the presence of a negative ETE signifies that knowledge of an equity index indicates a higher risk coverage for the others whilst a positive ETE implies that awareness of an equity index plunges the risk of the others (Adam, 2020; Asafo-Adjei *et al.*, 2022a). The study assigns high weight to the tails for low values of q. Hence, following extant literature, q from the Rényi effective transfer entropy (RETE) is set to 0.3 to offer more weights to the tails, which bears direct implications for revealing richer information at low probability events of extreme markets outcomes.

Since information flows between stock markets occur between the entire market and its constituents as well as other financial markets (Kwon and Yang, 2008; Osei and Adam, 2020), the study examines information flows between regional equities as constituents and global equities and advanced markets as the entire market. This is not overwhelming because stock markets operate in a nonisolated system, which interacts and exchanges information with the real economy (Osei and Adam, 2020). For this reason, information flows are presented between other ER and global indices such as S.PGBMI, DJSW, DJSWD and NGMCI. Findings are presented for S.PGBMI and NGMCI as proxies for global indices in sustainability and conventional equities, respectively, and the remaining global indices are attached as supplementary for comparison (see, Tables S2–S5).

Equities	Teraesvirta's neural network test (TRS) HFQ	MFQ	LFQ	RESID
DJAT	25.12**	0.09	12.46**	694.98**
DJIME	35.65**	0.53	1.11	7.02*
DJMENA	71.42**	2.08	4.76	15.88**
DJSAP	23.95**	0.12	7.48*	6256.40**
DJSE	39.18**	0.04	2.44	3707.20**
DJSEM	38.22**	0.09	0.01	33.95**
DJSEZ	20.24**	0.28	1.09	5715.50**
DJSNA	133.61**	0.36	5.95	538.45**
DJSUS	123.85**	0.13	1.98	403.76**
DJSW	79.07**	0.39	0.13	177.20**
DJSWD	80.84**	0.39	6.74*	3228.10**
S.PAA	19.14**	0.74	0.08	486.18**
S.PBRICT	59.79**	0.18	50.88**	4939.50**
S.PEA	4.11	0.11	26.14**	6569.90**
S.PFBMIS	19.61**	2.55	9.61**	6514.40**
S.PGBMI	118.74**	1.21	7.82*	1051.80**
S.PLABMI	160.58**	0.36	6.88*	4919.00**
S.PNA	46.19**	0.9	2.06	3620.40**
S.PPAFS	1.18	0.31	0.54	90.71**
S.PSSA	6.28*	0.01	2.11	3001.60**
NAMERICAI	129.79**	0.45	6.62*	0.02
NAREITs	41.64**	0.10	4.71	4.56
NASIAI	25.02**	0.15	5.11	944.81**
NBRICI	38.47**	0.11	1.30	1789.50**
NDMI	179.47**	5.52	2.41	5022.30**
NEMI	55.47**	0.12	12.56**	2120.70**
NEUROPI	2.78	0.62	53.21**	3702.60**
NEUROZI	17.15**	0.20	6.17*	286.98**
NGMCI	58.41**	0.32	2.82	10216.00**
NGVOLNDX	95.15**	1.15	0.07	2230.80**

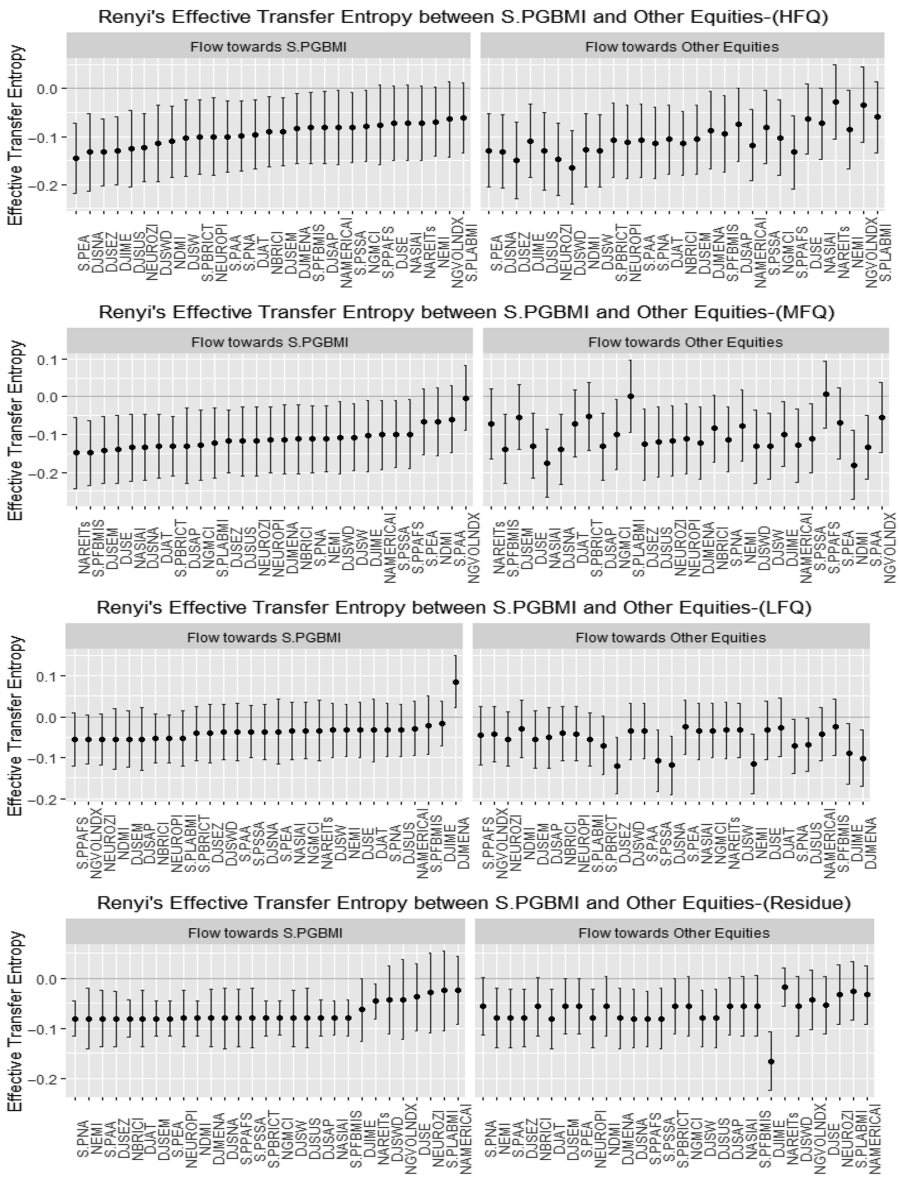
Note(s): [*; **] show significance levels at respectively 5 and 1%
Source(s): Table by authors

Table 3.
Linearity test of equity returns

Figure 3 displays information flows between S.PGBMI and the remaining 29 equities at multi-frequencies. It shows information flows towards S.PGBMI and flows from S.PGBMI. The findings provided here depict similar outcomes for DJSW, DJSWD and NGMCI as shown in supplementary. Numerical outputs of the information flows are shown in Table 4.

It can be seen that significant negative information is generally transmitted towards S.PGBMI and from S.PGBMI in the short, medium and long terms in addition to the residue as shown in Figure 3. The negative information flows even become more significant in the HFQ, MFQ and residue, highlighting their dominance in the information flow dynamics with S.PGBMI. A scan through the RETE plots indicates that NASDAQ 100 Volatility Target index (NVOLNDX) demonstrates the weakest flow of information with S.PGBMI. This implies that NVOLNDX as a measure of volatility index depicts less connectedness with S.PGBMI and with all other equities as presented in the supplementary files. This highlights the resistance of S.PGBMI as a proxy for global sustainability index against shocks from NVOLNDX. Accordingly, it becomes difficult for the S.PGBMI to be susceptible to contagion from NVOLNDX and vice versa.

As revealed by Asafo-Adjei *et al.* (2022b) on the significant positive correlation among the SEs at most frequencies driving their persisting convergence as found in the unconditional correlation matrix and wavelet multiple in the study of Asafo-Adjei *et al.* (2022c), information transmission among them is mostly rather negative and significant. This concurs the



Source(s): Figure by authors

Figure 3.
Multi-frequency information flows between S.PGBMI and other ER

findings by Asafo-Adjei *et al.* (2022a), Boateng *et al.* (2022), Bossman (2021) and Bossman *et al.* (2022a). This accentuates that knowledge of S.PGBMI indicates a higher risk coverage for the other ER and vice versa. This is pertinent for portfolio diversification in the sense that information transmitted from S.PGBMI plummets the performance of other ER in the short and medium term, as well as the long-term trend.

Equities	Flows towards global equities HFQ	MFQ	LFQ	RESID	Flows towards other equities HFQ	MFQ	LFQ	RESID
	S.PGBMI				Others			
DJAT	−0.096	−0.132	−0.033	−0.081	−0.106	−0.071	−0.027	−0.081
DJIME	−0.129	−0.103	−0.017	−0.063	−0.109	−0.099	−0.090	−0.166
DJMENA	−0.082	−0.113	0.086	−0.080	−0.087	−0.123	−0.101	−0.080
DJSAP	−0.081	−0.130	−0.054	−0.080	−0.075	−0.132	−0.051	−0.056
DJSE	−0.072	−0.139	−0.033	−0.038	−0.063	−0.130	−0.033	−0.053
DJSEM	−0.090	−0.141	−0.055	−0.081	−0.106	−0.054	−0.055	−0.056
DJSEZ	−0.133	−0.118	−0.041	−0.081	−0.149	−0.126	−0.119	−0.080
DJSNA	−0.133	−0.133	−0.037	−0.080	−0.131	−0.140	−0.119	−0.081
DJSUS	−0.125	−0.118	−0.033	−0.080	−0.130	−0.120	−0.069	−0.080
DJSW	−0.104	−0.108	−0.033	−0.080	−0.130	−0.131	−0.033	−0.080
DJSWD	−0.113	−0.108	−0.038	−0.043	−0.164	−0.132	−0.036	−0.056
S.PAA	−0.100	−0.059	−0.037	−0.081	−0.108	−0.133	−0.034	−0.080
S.PBRICT	−0.101	−0.131	−0.041	−0.080	−0.108	−0.052	−0.071	−0.056
S.PEA	−0.145	−0.066	−0.036	−0.081	−0.130	−0.070	−0.025	−0.056
S.PFBMIS	−0.082	−0.149	−0.021	−0.080	−0.094	−0.139	−0.025	−0.055
S.PLABMI	−0.061	−0.122	−0.054	−0.025	−0.060	0.001	−0.055	−0.026
S.PNA	−0.098	−0.112	−0.033	−0.081	−0.114	−0.113	−0.073	−0.056
S.PPAFS	−0.076	−0.099	−0.055	−0.080	−0.132	0.005	−0.046	−0.081
S.PSSA	−0.080	−0.099	−0.037	−0.080	−0.080	−0.110	−0.107	−0.081
NAMERICAI	−0.081	−0.101	−0.029	−0.025	−0.118	−0.129	−0.042	−0.033
NAREITs	−0.071	−0.149	−0.034	−0.046	−0.028	−0.072	−0.033	−0.017
NASIAI	−0.072	−0.135	−0.035	−0.080	−0.073	−0.175	−0.036	−0.056
NBRICI	−0.090	−0.112	−0.054	−0.081	−0.115	−0.084	−0.040	−0.056
NDMI	−0.110	−0.066	−0.055	−0.080	−0.128	−0.180	−0.031	−0.056
NEMI	−0.069	−0.111	−0.033	−0.081	−0.085	−0.077	−0.115	−0.080
NEUROPI	−0.100	−0.114	−0.054	−0.081	−0.111	−0.111	−0.042	−0.080
NEUROZI	−0.122	−0.118	−0.055	−0.029	−0.147	−0.116	−0.055	−0.033
NGMCI	−0.078	−0.129	−0.034	−0.080	−0.102	−0.101	−0.035	−0.056
NGVOLNDX	−0.064	−0.003	−0.055	−0.043	−0.034	−0.054	−0.043	−0.043
	NGMCI				Others			
DJAT	−0.103	−0.075	−0.025	−0.056	−0.119	−0.011	−0.047	−0.081
DJIME	−0.052	−0.096	−0.036	−0.056	−0.104	−0.104	−0.063	−0.079
DJMENA	−0.029	−0.014	−0.036	−0.056	−0.120	−0.147	−0.020	−0.080
DJSAP	−0.067	−0.181	−0.033	−0.094	−0.088	−0.185	−0.078	−0.094
DJSE	−0.099	−0.173	−0.054	−0.024	−0.086	−0.100	−0.054	−0.053
DJSEM	−0.040	−0.161	−0.033	−0.094	−0.112	−0.050	−0.034	−0.094
DJSEZ	−0.068	−0.031	−0.027	−0.047	−0.073	−0.114	−0.053	−0.065
DJSNA	−0.138	−0.140	−0.055	−0.056	−0.126	−0.034	−0.038	−0.080
DJSUS	−0.122	−0.085	−0.034	−0.056	−0.124	−0.075	−0.117	−0.081
DJSW	−0.101	−0.107	−0.044	−0.056	−0.091	−0.064	−0.048	−0.080
DJSWD	−0.092	−0.109	−0.033	−0.018	−0.057	−0.059	−0.038	−0.033
S.PAA	−0.084	−0.148	−0.055	−0.056	−0.093	−0.173	−0.055	−0.081
S.PBRICT	−0.093	−0.117	−0.044	−0.094	−0.086	−0.031	−0.070	−0.093
S.PEA	−0.126	−0.071	−0.024	−0.093	−0.091	−0.098	−0.023	−0.093
S.PFBMIS	−0.101	−0.131	−0.043	−0.093	−0.085	−0.089	−0.040	−0.093
S.PGBMI	−0.098	−0.108	−0.035	−0.056	−0.080	−0.123	−0.034	−0.081
S.PLABMI	−0.060	−0.119	−0.054	−0.040	−0.103	−0.114	−0.054	−0.059
S.PNA	−0.063	−0.073	−0.055	−0.094	−0.066	−0.151	−0.045	−0.093
S.PPAFS	−0.062	−0.075	−0.055	−0.056	−0.106	−0.050	−0.041	−0.081
S.PSSA	−0.071	−0.105	−0.038	−0.056	−0.088	−0.095	−0.104	−0.081

(*continued*)

Table 4. Multi-frequency entropy analysis of information flows between global equities and constituents

	NGMCI				Others			
NAMERICAI	−0.108	−0.112	−0.056	−0.017	−0.122	−0.031	−0.048	−0.034
NAREITs	−0.081	−0.115	−0.054	−0.032	−0.052	−0.077	−0.054	−0.017
NASIAI	−0.111	−0.137	−0.054	−0.093	−0.089	−0.126	−0.054	−0.094
NBRICI	−0.042	−0.127	−0.034	−0.093	−0.060	−0.007	−0.066	−0.093
NDMI	−0.093	−0.102	−0.042	−0.094	−0.084	−0.087	−0.021	−0.093
NEMI	−0.039	−0.024	−0.033	−0.056	−0.091	−0.111	−0.117	−0.080
NEUROPI	−0.060	−0.106	−0.055	−0.056	−0.089	−0.058	−0.042	−0.081
NEUROZI	−0.080	−0.091	−0.056	−0.056	−0.070	−0.090	−0.055	−0.081
NGVOLNDX	−0.012	−0.036	−0.025	−0.056	−0.077	0.089	−0.066	−0.081

Table 4. **Source(s):** Table by authors

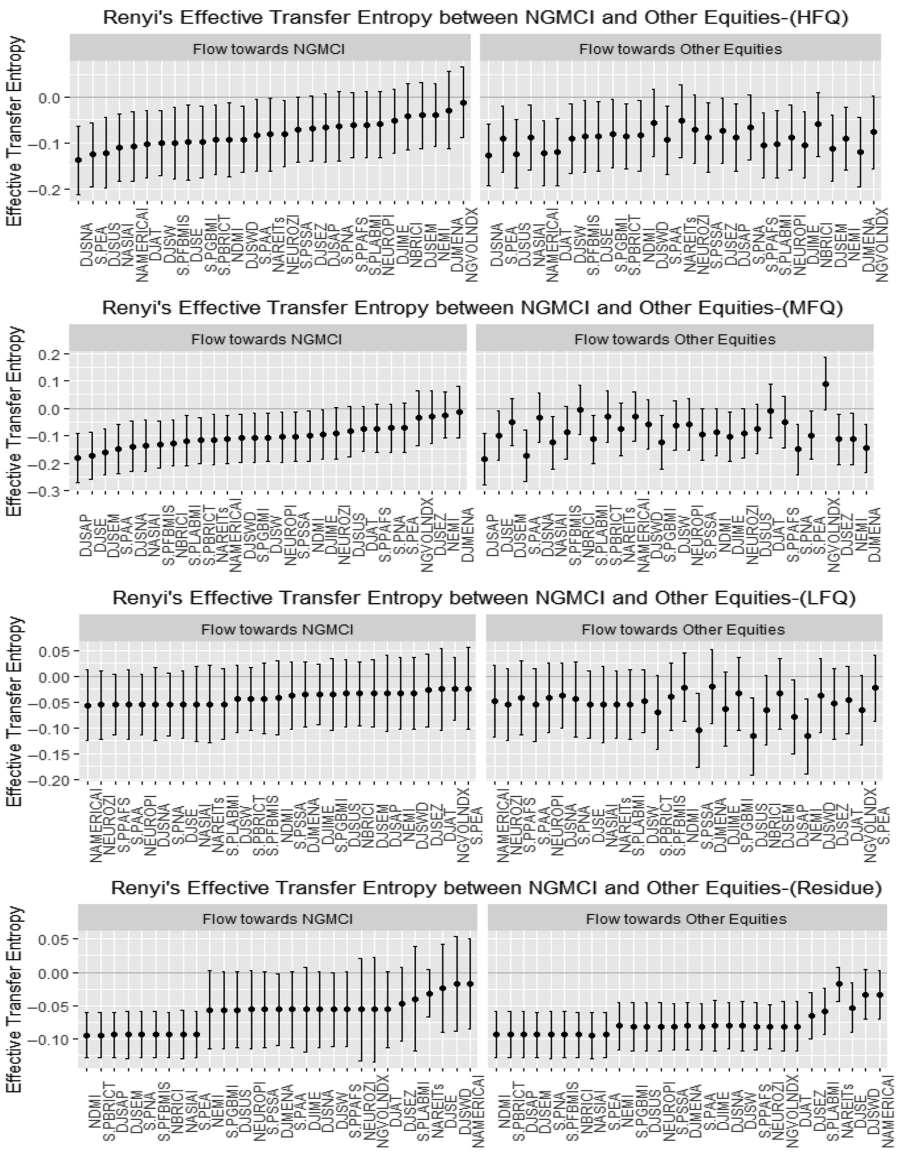
Nonetheless, the patterns of information flows among the SEs vary from one frequency to another as revealed numerous studies on information flows (Boateng *et al.*, 2022, Bossman, 2021; Bossman *et al.*, 2022a; Owusu Junior *et al.*, 2021b, etc.). Particularly, SEs transmit significant negative information towards S.PGBMI at the HFQ except for S.PLABMI, DJSE, S.PPAFS and S.PSSA, but except for S.PEA and S.PAA at the MFQ. At the LFQ, except for DJMENA, all the sustainability equity indices transmit no information to S.PGBMI. Moreover, the residue indicates that all sustainability equity indices but S.PLABMI, DJSE, DJSWD and DJIME transmit significant negative information to S.PGBMI. This demonstrates the degree to which sustainability equity securities using S.PGBMI as a worldwide index exhibit varied and adaptive behaviour. Given the large negative information flows between the returns of S.PGBMI and all other sustainability stocks, investors interested in SRI would choose to choose from a variety of SEs to build a trustworthy portfolio.

It can further be noticed that information flows for most SEs are bi-directional for HFQ, MFQ and residue. This shows that sustainability equity indices exhibit similar dynamics of information transfer to a global index. As such most of the sustainability equity indices can equally observe the behaviour of S.PGBMI from the standpoint of irrational investors at varying levels of multi-frequencies revealing markets inefficiencies.

However, the insignificant negative information flows at LFQ for most sustainability equity indices manifest that in the long term, the markets begin to submerge from their longstanding interactions to induce convoluting predictions which contradicts the outcome by Asafo-Adjei *et al.* (2022a) during the COVID-19 pandemic. Accordingly, the efficient adjustment of prices to information is a key feature of market circumstances. As a result, there is agreement among market participants at the LFQ regarding the significance of recent information for each security's present price and distribution of its future price (Fama, 1970). For logical investors who want to maximise their utility in accordance with Neoclassical theory, they would take advantage of the market by (1) identifying patterns in price fluctuations or information flows in the HFQ and MFQ and (2) purchasing the security to build dependable portfolios.

Nonetheless, as buying drives up the price of an asset and selling drives it down, the information the arbitrageur trader had about the market is mirrored in the asset prices, suggesting that there may be patterns that can be exploited but that are not permanent. This is due to the fact that reacting to information changes the pricing, which eliminates patterns as shown in the LFQ.

In comparison with conventional equities, Figure 4 presents information flows with NGMCI in across investment horizons. This would inform investors on the effective allocation of assets, rebalancing or redeployment of their portfolios in the short, medium and long terms with SRI and the conventional way of investing in perspective.



Source(s): Figure by authors

Figure 4.
Multi-frequency information flows between NGMCI and other equities

From Figure 4, we find similar significant flows of information among the equities as noticed in Figure 3. However, in the residue (very long term) information flows with the NGMCI as a global proxy for CE transmits and receives more negative information with both sustainability and conventional equity returns. On the other hand, in the short and medium frequencies, information flows with the S.PGBMI are more negative and significant relative to the NGMCI. Conversely, all the global indices demonstrate no significant information flows.

Having in mind, the wider representation of global indices, we advocate that information flows with SEs enhance diversification potentials in the short and medium terms, whereas information flows with CEs exacerbate diversification benefits in the long-term deterministic trend representing over 7 years of the sampled period on a 250 trading days. Hence, speculative investors of SEs can form a diversified portfolio in the very long term when they include relevant indices of CEs. On the other hand, short- and medium-term investors are better off with a diversified portfolio when they concentrate on SRI. Accordingly, existing investors of CEs can still maintain their portfolio choices but should have plans for considering SRI since its benefit exceeds the cost.

4.4 Discussion

The study revealed significant negative information flows toward S.PGBMI and from S.PGBMI in the short, medium and long terms in addition to the residue as found by existing studies on other financial assets but with some degree of differences in outcomes (Adam, 2020; Boateng *et al.*, 2022; Bossman, 2021; Bossman *et al.*, 2022a; Owusu Junior *et al.*, 2021b). The negative information flows even became more significant in the HFQ, MFQ and residue, highlighting their dominance in the information flow dynamics with S.PGBMI and NGMCI. This explains that knowledge of S.PGBMI and NGMCI designates a higher risk coverage for the other ER and vice versa, thereby magnifying diversification benefits. The study further found that information flows for most SEs are bi-directional for HFQ, MFQ and residue confirming the similar dynamics of information flows to a global index despite their asymmetric behaviour regarding volatilities (Irfan *et al.*, 2021). The SEs, however, depict asymmetric relationships from one frequency to another. As such most of the sustainability equity indices can equally observe the behaviour of S.PGBMI at varying levels of multi-frequencies. Accordingly, investors can form reliable portfolio by concentrating information flow between the global and constituents' assets at the high and medium frequencies and residue representing short-, medium-, and very long-term dynamics.

Nonetheless, the insignificant negative information flows at LFQ for most sustainability equity indices manifest that in the long term, the markets begin to submerge their longstanding interactions to hinder predictions or exploitations of patterns. At the low frequency, this may prohibit analysts who aspire to be with a firm based on the firm's inclusion on the sustainability index as found by Durand *et al.* (2019). However, exploitation of the market becomes advantageous to short- and medium-term investors as well as the very long-term representing over 7 years on about 250 trading days for long-term investors and institutional investors alike. Generally, the examination of CSR activities is an impetus or important requirement for asset allocation as averred by Consolandi *et al.* (2009) and Helliar *et al.* (2022).

5. Conclusions

This study investigated information flows among constituents and global – sustainability and conventional equity returns across investment horizons. For this reason, a multi-frequency-dependent technique was employed to address the heterogeneous (Müller *et al.*, 1997) and adaptive (Lo, 2004) behaviours. Accordingly, the I-CEEMDAN-based cluster analysis RETE were utilised in this study. The study's analyses were mostly focused on sustainability-related stocks in comparison to conventional stocks. The daily data, which included 2,102 observations, run from November 12th, 2012 to December 2nd, 2021.

We found significant information flows among the constituents and their global indices. Information flow for most sustainability and conventional equity returns were found to be negative and bidirectional at multi-frequencies, except for the low frequency.

The study concludes that negative information transmission between constituents of SEs and their global index is multi-frequency dependent. The knowledge of a global index indicates a higher risk coverage for sustainability equity returns as constituents and vice versa to warrant diversification benefits. Moreover, the information the arbitrageur trader had concerning the market in the short and medium terms is reflected in the asset prices, suggesting that indeed there could be patterns that can be exploited, but not everlasting. This explains that the behaviour of the markets is heterogeneous and adaptive due to the behavioural intentions of market participants, especially in the short and medium terms, but this effect dissipates in the low frequency suggesting markets efficiency. Overall, the markets are inefficient at various frequencies of varying dynamics but become efficient only at the low frequency (long term) in terms of unpredictable patterns of information flows.

It is suggested that rational investors who want to maximise their utility in accordance with Neoclassical theory should take advantage of the market in the following ways: (1) identify patterns in short- and medium-term price changes or information flows and (2) buy the security to build reliable portfolios. This is pertinent because the exploited patterns are not persisting. Consequently, responding to the information affects the prices which induce the patterns to be expunged as witnessed in the low frequency. For reliable portfolio returns, it is important for investors to form portfolio between the global and constituents' assets at the high and medium frequency and residue representing short-, medium- and very long-term dynamics.

Future research can focus on information flow among sustainability stocks before and during the COVID-19 era to examine how it affected the pre-existing connections. Moreover, studies may delve into regional blocs to examine the pattern of country or firm-specific similarities, interdependencies and information flows among sustainability equity indices.

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Supplementary materials

SN	Sustainability equity indices	Code
1	Dow Jones Africa Titans 50 Index	DJAT
2	Dow Jones Islamic Market Europe Index	DJIME
3	Dow Jones MENA Index	DJMENA
4	Dow Jones Sustainability Asia Pacific Index	DJSAP
5	Dow Jones Sustainability Europe Index	DJSE
6	Dow Jones Sustainability Emerging Markets Index	DJSEM
7	Dow Jones Sustainability Eurozone Region Index	DJSEZ
8	Dow Jones Sustainability North America Index	DJSNA
9	Dow Jones Sustainability U.S. Index	DJSUS
10	Dow Jones Sustainability World Index	DJSW
11	Dow Jones Sustainability World Developed Index	DJSWD
12	S&P All Africa	S.PAA
13	S&P BRICT Index	S.PBRICT
14	S&P East Africa	S.PEA
15	S&P Frontier BMI Shariah	S.PFBMIS
16	S&P Global BMI	S.PGBMI
17	S&P Latin America BMI	S.PLABMI
18	S&P North Africa	S.PNA
19	S&P Africa Frontier Shariah Index	S.PPAFS
20	S&P All Sub-Saharan Africa ex-South Africa Index	S.PSSA
Control variables (conventional equities)		
1	NASDAQ America Index	NAMERICAI
2	NAREIT Global Real Estate Index	NAREITs
3	NASDAQ ASIA Index	NASIAI
4	NASDAQ BRIC Index	NBRICI
5	NASDAQ Developed Markets Index	NDMI
6	NASDAQ Emerging Markets Index	NEMI
7	NASDAQ Europe Index	NEUROPI
8	NASDAQ Eurozone Index	NEUROZI
9	NASDAQ Global Market Composite Index	NGMCI
10	NASDAQ 100 Volatility Target	NGVOLNDX

Source(s): Table by authors

Table S1.
Equity indices

Equities	Flows towards global equities HFQ	MFQ	LFQ	RESID	Flows towards other equities HFQ	MFQ	LFQ	RESID
	DJSW				Others			
DJAT	−0.110	−0.137	−0.051	−0.081	−0.064	−0.138	−0.033	−0.080
DJIME	−0.122	−0.132	−0.019	−0.062	−0.132	−0.132	−0.137	−0.111
DJMENA	−0.068	−0.101	−0.033	−0.080	−0.100	−0.101	−0.017	−0.080
DJSAP	−0.124	−0.147	−0.054	−0.081	−0.077	−0.090	−0.050	−0.055
DJSE	−0.081	−0.157	−0.054	−0.036	−0.043	−0.116	−0.055	−0.054
DJSEM	−0.111	−0.177	−0.015	−0.081	−0.108	−0.134	−0.017	−0.056
DJSEZ	−0.137	−0.072	−0.033	−0.081	−0.108	−0.101	−0.060	−0.081
DJSNA	−0.151	−0.141	−0.055	−0.082	−0.134	−0.135	−0.044	−0.081
DJSUS	−0.153	−0.137	−0.033	−0.059	−0.142	−0.078	−0.071	−0.058
DJSWD	−0.109	−0.182	−0.038	−0.042	−0.103	−0.178	−0.042	−0.054
S.PAA	−0.135	−0.118	−0.054	−0.067	−0.141	−0.146	−0.054	−0.072
S.PBRICT	−0.108	−0.123	−0.038	−0.081	−0.081	−0.039	−0.076	−0.055
S.PEA	−0.132	−0.061	−0.039	−0.081	−0.101	−0.070	−0.033	−0.056
S.PFBMIS	−0.084	−0.106	−0.037	−0.081	−0.085	−0.134	−0.036	−0.055
S.PGBMI	−0.130	−0.136	−0.034	−0.081	−0.107	−0.116	−0.033	−0.081
S.PLABMI	−0.118	−0.126	−0.056	−0.025	−0.107	−0.109	−0.055	−0.026
S.PNA	−0.008	−0.080	−0.054	−0.081	−0.097	−0.110	−0.095	−0.056
S.PPAFS	−0.069	−0.032	−0.055	−0.056	−0.081	−0.070	−0.049	−0.064
S.PSSA	−0.133	−0.130	−0.018	−0.081	−0.065	−0.122	−0.122	−0.081
NAMERICAI	−0.151	−0.138	−0.043	−0.010	−0.136	−0.114	−0.040	−0.013
NAREITs	−0.079	−0.136	−0.055	−0.046	−0.060	−0.095	−0.055	−0.017
NASIAI	−0.109	−0.149	−0.054	−0.081	−0.045	−0.128	−0.055	−0.055
NBRICI	−0.083	−0.123	−0.016	−0.080	−0.102	−0.075	−0.046	−0.056
NDMI	−0.148	−0.117	−0.055	−0.081	−0.145	−0.070	−0.036	−0.056
NEMI	−0.089	−0.163	−0.055	−0.081	−0.075	−0.126	−0.037	−0.080
NEUROPI	−0.118	−0.124	−0.055	−0.080	−0.097	−0.118	−0.042	−0.080
NEUROZI	−0.130	−0.124	−0.034	−0.042	−0.115	−0.123	−0.033	−0.042
NGMCI	−0.099	−0.065	−0.049	−0.081	−0.095	−0.109	−0.044	−0.056
NGVOLNDX	0.008	0.046	−0.022	−0.042	−0.021	−0.009	−0.046	−0.043
	DJSWD				Others			
DJAT	−0.072	−0.170	−0.038	−0.055	−0.042	−0.157	−0.024	−0.042
DJIME	−0.121	−0.129	−0.019	−0.054	−0.128	−0.140	−0.090	−0.033
DJMENA	−0.070	−0.102	−0.035	−0.055	−0.104	−0.106	−0.025	−0.042
DJSAP	−0.127	−0.130	−0.054	−0.033	−0.092	−0.139	−0.049	−0.018
DJSE	−0.058	−0.144	−0.055	−0.055	−0.048	−0.111	−0.055	−0.054
DJSEM	−0.078	−0.171	−0.037	−0.033	−0.067	−0.143	−0.039	−0.017
DJSEZ	−0.093	−0.065	−0.055	−0.037	−0.086	−0.095	−0.030	−0.029
DJSNA	−0.148	−0.144	−0.033	−0.055	−0.127	−0.129	−0.070	−0.042
DJSUS	−0.157	−0.133	−0.055	−0.054	−0.135	−0.118	−0.046	−0.042
DJSW	−0.106	−0.177	−0.042	−0.054	−0.107	−0.180	−0.038	−0.043
S.PAA	−0.105	−0.117	−0.055	−0.055	−0.115	−0.114	−0.055	−0.042
S.PBRICT	−0.100	−0.121	−0.055	−0.033	−0.052	−0.043	−0.043	−0.018
S.PEA	−0.128	−0.067	−0.055	−0.033	−0.100	−0.116	−0.042	−0.017
S.PFBMIS	−0.093	−0.115	−0.033	−0.033	−0.094	−0.133	−0.033	−0.017
S.PGBMI	−0.158	−0.135	−0.036	−0.055	−0.117	−0.111	−0.037	−0.042
S.PLABMI	−0.100	−0.134	−0.034	−0.033	−0.084	−0.117	−0.032	−0.026

Table S2.
Multi-frequency entropy analysis of information flows between other global equities and constituents

(*continued*)

	DJSWD				Others			
S.PNA	−0.045	−0.074	−0.055	−0.033	−0.121	−0.114	−0.044	−0.017
S.PPAFS	−0.062	−0.070	−0.054	−0.055	−0.086	−0.066	−0.048	−0.042
S.PSSA	−0.092	−0.133	−0.055	−0.055	−0.069	−0.117	−0.089	−0.042
NAMERICAI	−0.153	−0.143	−0.034	−0.055	−0.127	−0.114	−0.033	−0.055
NAREITs	−0.089	−0.131	−0.055	−0.042	−0.064	−0.101	−0.055	−0.012
NASIAI	−0.099	−0.142	−0.054	−0.032	−0.075	−0.130	−0.054	−0.017
NBRICI	−0.071	−0.079	−0.036	−0.033	−0.098	−0.024	−0.022	−0.017
NDMI	−0.153	−0.132	−0.055	−0.033	−0.152	−0.085	−0.031	−0.017
NEMI	−0.056	−0.152	−0.055	−0.055	−0.055	−0.130	−0.036	−0.042
NEUROPI	−0.069	−0.119	−0.055	−0.032	−0.062	−0.126	−0.042	−0.026
NEUROZI	−0.093	−0.111	−0.034	−0.033	−0.073	−0.118	−0.035	−0.026
NGMCI	−0.052	−0.060	−0.037	−0.033	−0.089	−0.104	−0.033	−0.017
NGVOLNDX	−0.005	0.051	−0.036	−0.033	−0.015	−0.002	−0.117	−0.026

Source(s): Table by authors

Table S2.

Table S3.
Sustainability equity (Dow Jones) measures of IMF's obtained through I-CEEMDAN

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMF9	IMF10	RESID
						DJAT					
μ	2.79	5.70	11.24	22.85	44.72	75.07	161.69	300.29	420.40	700.67	
ρ	0.71**	0.5**	0.41**	0.25**	0.22**	0.11**	0.12**	0.05**	0.05*	0.01	−0.01
σ_1^2	50.93%	17.13%	12.06%	6.67%	4.69%	1.29%	1.19%	0.70%	0.33	0.03%	0.01%
σ_2^2	50.93%	17.13%	12.06%	6.67%	4.69%	1.29%	1.19%	0.70%	0.33	0.03%	0.01%
						DJIME					
μ	2.75	5.65	10.89	20.61	36.88	70.07	140.13	210.20	350.33	525.50	
ρ	0.74**	0.45**	0.32**	0.20**	0.17**	0.12**	0.10**	0.04*	0.04*	0.01	−0.02
σ_1^2	59.78%	20.90%	12.08%	6.77%	2.80%	1.42%	1.11%	0.27%	0.40%	0.06%	0.01%
σ_2^2	59.78%	20.90%	12.08%	6.77%	2.80%	1.42%	1.11%	0.27%	0.40%	0.06%	0.01%
						DJMENA					
μ	2.68	5.35	10.72	20.02	38.22	67.81	105.10	175.17	262.75	420.40	
ρ	0.68**	0.50**	0.32**	0.24**	0.19**	0.15**	0.10**	0.08**	0.04*	0.08**	0.03
σ_1^2	50.58%	24.60%	10.10%	5.98%	5.29%	3.58%	1.32%	1.64%	0.68%	1.0%	0.13%
σ_2^2	50.58%	24.60%	10.10%	5.98%	5.29%	3.58%	1.32%	1.64%	0.68%	1.0%	0.13%
						DJSAP					
μ	2.74	5.53	10.62	21.45	40.42	84.08	140.13	233.56	420.4	525.50	
ρ	0.72**	0.49**	0.34**	0.24**	0.15**	0.12**	0.10**	0.05*	0.03	0.01	0.01
σ_1^2	54.97%	23.40%	10.74%	7.91%	2.65%	1.69%	0.72%	0.51%	0.02%	0.02%	0.01%
σ_2^2	54.97%	23.40%	10.74%	7.91%	2.65%	1.69%	0.72%	0.51%	0.02%	0.02%	0.01%
						DJSE					
μ	2.72	5.52	10.95	21.23	40.42	70.07	116.78	191.09	300.29	420.40	
ρ	0.76**	0.44**	0.33**	0.21**	0.18**	0.12**	0.09**	0.06**	0.05*	0.02	−0.01
σ_1^2	60.38%	17.44%	11.26%	7.25%	3.20%	1.43%	0.70%	0.26%	0.18%	0.04%	0.02%
σ_2^2	60.38%	17.44%	11.26%	7.25%	3.20%	1.43%	0.70%	0.26%	0.18%	0.04%	0.02%
						DJSEM					
μ	2.80	5.87	11.68	23.36	50.05	95.55	175.17	300.29	420.40	700.67	
ρ	0.73**	0.49**	0.36**	0.26**	0.17**	0.14**	0.09**	0.06**	0.03	0.01	0.02
σ_1^2	52.72%	19.31%	10.42%	6.56%	3.84%	2.71%	0.85%	0.51%	0.28%	0.17%	0.01%
σ_2^2	52.72%	19.31%	10.42%	6.56%	3.84%	2.71%	0.85%	0.51%	0.28%	0.17%	0.01%

(*continued*)

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMF9	IMF10	RESID
						DJSEZ					
μ	2.71	5.59	10.62	20.81	38.22	77.85	161.69	300.29	420.40	700.67	
ρ	0.73**	0.46**	0.37**	0.23**	0.19**	0.13**	0.07**	0.05*	0.01	0.01	−0.01
σ_1^2	55.97%	18.07%	13.18%	5.47%	3.86%	2.49%	1.55%	0.23%	0.12%	0.09%	0.02%
σ_2^2	55.97%	18.07%	13.18%	5.47%	3.86%	2.49%	1.55%	0.23%	0.12%	0.09%	0.02%
						DJSNA					
μ	2.73	5.36	10.20	18.94	35.63	61.82	110.63	161.69	300.29	420.40	
ρ	0.82**	0.40**	0.31**	0.21**	0.17**	0.13**	0.08**	0.05*	0.04*	0.01	0.02
σ_1^2	66.12%	12.71%	8.63%	3.93%	3.20%	1.47%	1.13%	0.42%	0.21%	0.03%	0.01%
σ_2^2	66.12%	12.71%	8.63%	3.93%	3.20%	1.47%	1.13%	0.42%	0.21%	0.03%	0.01%
						DJSUS					
μ	2.74	5.29	10.11	18.44	33.37	60.06	105.10	175.17	300.29	420.40	
ρ	0.82**	0.40**	0.30**	0.20**	0.17**	0.13**	0.09**	0.04*	0.03	0.02	0.02
σ_1^2	66.85%	13.02%	8.35%	3.51%	3.32%	1.60%	1.10%	0.27%	0.18%	0.06%	0.16%
σ_2^2	66.85%	13.02%	8.35%	3.51%	3.32%	1.60%	1.10%	0.27%	0.18%	0.06%	0.16%
						DJSW					
μ	2.79	5.68	10.89	20.81	36.24	63.70	116.78	150.14	350.33	525.50	
ρ	0.76**	0.47**	0.36**	0.20**	0.20**	0.14**	0.09**	0.06**	0.05*	0.03	0.02
σ_1^2	55.33%	15.63%	11.41%	7.13%	4.08%	1.73%	1.07%	0.50%	0.38%	0.02%	0.01%
σ_2^2	55.33%	15.63%	11.41%	7.13%	4.08%	1.73%	1.07%	0.50%	0.38%	0.02%	0.01%
						DJSWD					
μ	2.78	5.70	10.89	20.02	37.54	65.69	123.65	210.20	300.36	420.40	
ρ	0.76**	0.47**	0.35**	0.20**	0.20**	0.13**	0.09**	0.04*	0.04*	0.04*	0.01
σ_1^2	55.95%	15.58%	10.82%	7.03%	4.60%	1.71%	1.2%	0.26%	0.24%	0.10%	0.05%
σ_2^2	55.95%	15.58%	10.82%	7.03%	4.60%	1.71%	1.2%	0.26%	0.24%	0.10%	0.05%

Note(s): μ, ρ, σ_1^2 and σ_2^2 denote mean period, Pearson product moment correlations, variance as % of observed and variance as % of the sum of all IMFs and residue. [*; **] show significance levels at 5 and 1% respectively

Source(s): Table by authors

Table S3.

Table S4. Sustainability equities (S&P) measures of IMFs obtained through I-CEEMDAN

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMFF9	IMF10	RESID
						S.PAA					
μ	2.75	5.40	10.41	20.41	39.66	65.69	116.78	191.09	300.29	525.5	
ρ	0.75**	0.47**	0.34**	0.24**	0.17**	0.13**	0.11**	0.07**	0.06**	0.03	−0.01
σ_1^2	56.18%	15.54%	11.72%	7.26%	3.20%	2.02%	1.16%	0.64%	0.64%	0.15%	0.09%
σ_2^2	56.18%	15.54%	11.72%	7.26%	3.20%	2.02%	1.16%	0.64%	0.64%	0.15%	0.09%
						S.PBRICT					
μ	2.80	5.86	11.61	23.62	47.77	100.10	191.09	350.33	420.40	525.50	
ρ	0.75**	0.47**	0.33**	0.22**	0.16**	0.13**	0.09**	0.04*	0.02	−0.01	−0.01
σ_1^2	55.59%	20.55%	12.71%	5.43%	3.31%	0.03%	0.94%	0.33%	0.10%	0.02%	0.01%
σ_2^2	55.59%	20.55%	12.71%	5.43%	3.31%	0.03%	0.94%	0.33%	0.10%	0.02%	0.01%
						S.PEA					
μ	2.89	5.67	10.89	21.90	42.04	77.85	150.14	233.56	420.40	700.67	
ρ	0.62**	0.52**	0.41**	0.31**	0.19**	0.18**	0.11**	0.10**	0.08**	0.01	0.02
σ_1^2	55.59%	20.55%	12.71%	5.43%	3.31%	0.03%	0.94%	0.33%	0.10%	0.02%	0.01%
σ_2^2	55.59%	20.55%	12.71%	5.43%	3.31%	0.03%	0.94%	0.33%	0.10%	0.02%	0.01%
						S.PFBMIS					
μ	2.70	5.65	11.55	21.67	39.66	75.07	150.14	300.29	420.40	700.67	
ρ	0.74**	0.45**	0.33**	0.20**	0.15**	0.13**	0.10**	0.09**	0.06**	0.02	0.01
σ_1^2	54.98%	18.83%	12.02%	6.33%	2.43%	5.74%	2.98%	2.51%	0.58%	0.29%	0.07%
σ_2^2	54.98%	18.83%	12.02%	6.33%	2.43%	5.74%	2.98%	2.51%	0.58%	0.29%	0.07%
						S.PGBMI					
μ	2.79	5.77	11.06	19.64	34.46	63.70	116.78	191.09	350.33	525.50	
ρ	0.74**	0.48**	0.34**	0.25**	0.19**	0.15**	0.10**	0.05**	0.05*	0.04*	0.02
σ_1^2	54.48%	16.35%	10.22%	6.21%	4.35%	3.23%	1.74%	0.30%	0.27%	0.17%	0.04%
σ_2^2	54.48%	16.35%	10.22%	6.21%	4.35%	3.23%	1.74%	0.30%	0.27%	0.17%	0.04%
						S.PLABMI					
μ	2.75	5.43	10.41	20.02	35.63	70.07	123.65	262.75	350.33	700.67	
ρ	0.77**	0.49**	0.33**	0.22**	0.14**	0.14**	0.11**	0.07**	0.05*	0.03	−0.01
σ_1^2	55.70%	15.51%	9.93%	5.05%	3.80%	4.67%	1.43%	0.90%	0.30%	0.32%	0.01%
σ_2^2	55.70%	15.51%	9.93%	5.05%	3.80%	4.67%	1.43%	0.90%	0.30%	0.32%	0.01%

(*continued*)

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMFF9	IMF10	RESID
						S.PNA					
μ	2.78	5.62	10.95	21.67	42.04	87.58	150.14	210.40	300.29	700.67	
ρ	0.63***	0.50***	0.39***	0.25***	0.16***	0.13***	0.08***	0.09***	0.05*	0.03	0.01
σ_1^2	48.84%	24.30%	17.56%	8.56%	4.13%	3.35%	1.60%	1.47%	0.49%	0.20%	0.02%
σ_2^2	48.84%	24.30%	17.56%	8.56%	4.13%	3.35%	1.60%	1.47%	0.49%	0.20%	0.02%
						S.PPAFS					
μ	2.76	5.40	10.20	20.41	36.88	70.07	131.38	262.75	300.29	420.40	
ρ	0.68***	0.48***	0.36***	0.25***	0.17***	0.12***	0.12***	0.08***	0.08***	0.08***	0.04*
σ_1^2	53.04%	20.18%	12.90%	6.46%	4.92%	3.23%	2.62%	1.42%	0.10%	0.54%	0.30%
σ_2^2	53.04%	20.18%	12.90%	6.46%	4.92%	3.23%	2.62%	1.42%	0.10%	0.54%	0.30%
						S.PSSA					
μ	2.82	5.68	11.49	22.13	40.42	67.81	116.78	175.17	300.29	525.50	
ρ	0.68***	0.53***	0.35***	0.24***	0.20***	0.18***	0.14***	0.07***	0.06***	0.06***	0.03
σ_1^2	46.51%	22.67%	11.85%	6.80%	3.70%	3.39%	1.70%	0.37%	0.64%	0.47%	0.02%
σ_2^2	46.51%	22.67%	11.85%	6.80%	3.70%	3.39%	1.70%	0.37%	0.64%	0.47%	0.02%

Note(s): [*, **] show significance levels at 5 and 1%, respectively
Source(s): Table by authors

Table S4.

Table S5.
Conventional equities (NASDAQ) measures of IMFs obtained through I-CEEMDAN

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMF9	IMF10	RESID
						NAMERICAI					
μ	2.73	5.24	10.25	18.44	32.84	61.82	116.78	210.20	350.33	420.40	
ρ	0.81**	0.40**	0.31**	0.19**	0.16**	0.13**	0.08**	0.03	0.02	0.03	0.02
σ_1^2	63.40%	12.85%	11.35%	3.96%	3.44%	2.77%	1.10%	0.23%	0.05%	0.08%	0.04%
σ_2^2	63.40%	12.85%	11.35%	3.96%	3.44%	2.77%	1.10%	0.23%	0.05%	0.08%	0.04%
						NAREITs					
μ	2.70	5.50	10.20	19.46	37.54	67.81	123.65	210.20	350.33	525.50	
ρ	0.78**	0.46**	0.23**	0.24**	0.15**	0.11**	0.08**	0.04*	0.04*	0.01	−0.01
σ_1^2	61.04%	19.44%	9.72%	8.36%	2.57%	1.26%	1.05%	0.25%	0.14%	0.01%	0.01%
σ_2^2	61.04%	19.44%	9.72%	8.36%	2.57%	1.26%	1.05%	0.25%	0.14%	0.01%	0.01%
						NASIAI					
μ	2.69	5.47	10.56	21.45	39.66	70.07	150.14	300.29	420.40	420.40	
ρ	0.72**	0.50**	0.37**	0.24**	0.17**	0.12**	0.10**	0.06**	0.03	0.01	0.01
σ_1^2	52.34%	20.97%	12.34%	7.46%	2.85%	1.30%	1.20%	0.30%	0.09%	0.02%	0.01%
σ_2^2	52.34%	20.97%	12.34%	7.46%	2.85%	1.30%	1.20%	0.30%	0.09%	0.02%	0.01%
						NBRICI					
μ	2.76	5.89	11.74	23.10	43.79	87.58	150.14	300.29	420.40	700.67	
ρ	0.75**	0.47**	0.37**	0.23**	0.16**	0.17**	0.08**	0.06**	0.03	0.01	−0.01
σ_1^2	55.19%	16.61%	11.46%	6.08%	2.34%	3.23%	0.66%	0.63%	0.26%	0.07%	0.01%
σ_2^2	55.19%	16.61%	11.46%	6.08%	2.34%	3.23%	0.66%	0.63%	0.26%	0.07%	0.01%
						NDMI					
μ	2.83	5.65	10.56	18.77	33.36	61.82	100.10	175.17	350.33	700.67	
ρ	0.75**	0.45**	0.36**	0.18**	0.16**	0.13**	0.10**	0.06**	0.05*	0.02	0.01
σ_1^2	57.23%	14.39%	12.15%	6.50%	6.60%	2.96%	2.10%	0.31%	0.44%	0.12%	0.04%
σ_2^2	57.23%	14.39%	12.15%	6.50%	6.60%	2.96%	2.10%	0.31%	0.44%	0.12%	0.04%
						NEMI					
μ	2.81	6.01	12.22	23.62	42.90	84.08	131.38	233.56	350.33	525.50	
ρ	0.74**	0.47**	0.36**	0.21**	0.19**	0.15**	0.13**	0.06**	0.05*	0.01	0.01
σ_1^2	53.96%	17.40%	11.69%	6.11%	3.22%	2.04%	2.04%	0.84%	0.81%	0.18%	0.05%
σ_2^2	53.96%	17.40%	11.69%	6.11%	3.22%	2.04%	2.04%	0.84%	0.81%	0.18%	0.05%

(*continued*)

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMF9	IMF10	RESID
						NEUROPI					
μ	2.74	5.62	10.72	19.28	36.88	65.69	105.10	191.09	350.33	700.67	
ρ	0.72**	0.45**	0.35**	0.24**	0.16**	0.12**	0.10**	0.60**	0.03	0.01	0.01
σ_1^2	58.16%	20.48%	12.05%	6.28%	2.79%	1.67%	1.16%	1.01%	0.49%	0.14%	0.07%
σ_2^2	58.16%	20.48%	12.05%	6.28%	2.79%	1.67%	1.16%	1.01%	0.49%	0.14%	0.07%
						NEUROZI					
μ	2.71	5.64	10.95	20.41	39.66	67.81	116.78	191.10	300.29	420.40	
ρ	0.73**	0.47**	0.37**	0.21**	0.17**	0.13**	0.09**	0.07**	0.05*	0.03	0.02
σ_1^2	55.73%	19.16%	12.88%	4.66%	4.35%	2.29%	1.44%	0.68%	0.16%	0.09%	0.01%
σ_2^2	55.73%	19.16%	12.88%	4.66%	4.35%	2.29%	1.44%	0.68%	0.16%	0.09%	0.01%
						NGMCI					
μ	2.75	5.45	11.12	19.64	38.93	80.85	131.38	262.75	420.40	700.67	
ρ	0.78**	0.44**	0.37**	0.24**	0.16**	0.12**	0.08**	0.06**	0.03	0.02	−0.01
σ_1^2	57.74%	13.67%	11.77%	6.03% %	3.19%	2.21%	0.70%	0.39%	0.21%	0.01%	0.01%
σ_2^2	57.74%	13.67%	11.77%	6.03% %	3.19%	2.21%	0.70%	0.39%	0.21%	0.01%	0.01%
						NGVOLNDX					
μ	2.94	5.50	10.72	20.61	34.46	56.81	87.58	161.69	262.75	525.50	
ρ	0.73**	0.41**	0.18**	0.10**	0.06**	0.01	0.01	0.01	0.01	−0.01	0.01
σ_1^2	77.94%	38.55%	14.70%	5.36%	2.90%	2.12%	3.42%	0.63%	0.01%	0.01%	0.01%
σ_2^2	77.94%	38.55%	14.70%	5.36%	2.90%	2.12%	3.42%	0.63%	0.01%	0.01%	0.01%

Note(s): [*, **] show significance levels at 5 and 1%, respectively
Source(s): Table by authors

Table S5.

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Simultaneous consideration of consumer preferences and seller revenue as a smart retail sales and management strategy

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Abstract

Purpose – The authors propose a dairy bundle, integrating strategies to jointly maximise producer revenue and consumer utility according to the latter's preferences.

Design/methodology/approach – An algorithm based on a nested logit model identifies the bundle maximising producer revenue based on factors affecting consumer purchase behaviour. The data are drawn from a mall-intercept survey administered in Iran, with consumers stating a hypothetical choice among a comprehensive set of dairy products.

Findings – Demographic characteristics and marketing mix elements significantly affect consumers' preferences. An algorithm based on the estimated dissimilarity parameter determines the best bundle of dairy products, simultaneously obtaining the highest utility and the highest expected revenue.

Originality/value – Consumer preference and maximum producer or retail seller income are considered simultaneously. The bundling promotion strategy is widely used for food offerings and fresh foods and can be extended to other products.

Keywords Dairy product bundling, Consumer preferences, Optimisation algorithm, Nested logit model

Paper type Research paper

1. Introduction

An adequate diet, which includes dairy products, can have a significant positive impact on human health (UNEP, 2019). These products are recommended for their important nutritional properties (Merlino *et al.*, 2022). Dairy products have a high share in the agricultural products industry and play an important role in the economy of many countries (Cabrera *et al.*, 2008). Despite new trends leading to steady growth in developed countries, dairy consumption is still low in some countries, such as Iran. For instance, there is a large gap in average per capita milk consumption between Iran (110 kg) and European countries (350 kg) (Singh and Gandhi, 2015). Therefore, a persuasive strategy is needed to encourage consumers to consume more of this beneficial product.

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Bundling, which consists of presenting a set of purchase items as a combined product package, can be used as a persuasion strategy. Bundling strategies are often used for food offerings (Stremersch and Tellis, 2002). As a marketing approach, bundling can identify and meet consumer needs, including needs, expectations, likes, dislikes, motivations and preferences that influence purchasing decisions (Spacey, 2016). In bundle pricing, companies and organisations sell a set of goods or services at a total price lower than the sum of the prices of the individual items. Bundling reduces search, sorting and processing costs (Hayes, 1987); extracts surplus from consumers (Janiszewski and Marcus Cunha, 2004); increases consumer purchase intentions and perceived value (Arora, 2008); helps manufacturers and companies offer different products and services (Dominique-Ferreira *et al.*, 2016); and also leads to perceptions of price fairness (Li *et al.*, 2018).

Previous research has demonstrated that it is a very effective and beneficial marketing technique that can generate more revenue and profit as well as higher and faster sales through revenue management (Chiambaretto and Dumez, 2012; Yan *et al.*, 2014). Product bundling can also attract consumers who like to make combined, value-oriented purchases. Product bundles allow consumers to access multiple available options by choosing a single package. Consumers are often more satisfied with a single choice from multiple items (Lloyd, 2016). This strategy has also attracted increasing attention in online sales, stimulating consumers to buy more than one product.

Despite the increasing use of the bundling strategy, few studies have been conducted on purchase motivation and consumer preferences for products sold in bundles (Liu *et al.*, 2017). Gandal *et al.* (2018) found that one of the keys to increasing profitability for producers and consumers as a win-win strategy is considering consumer preferences for products. The savings achieved by purchasing a bundle are attributed to increased value added (Sheng and Pan, 2009). As a result, companies can further invest in bundles to increase consumer satisfaction (Gandal *et al.*, 2018). Liu *et al.* (2017) investigated the relationships among products in a bundle that can effectively improve their joint performance. Their results show that consumer satisfaction can be maximised if preferences and the appropriate combination of products in the bundle are considered simultaneously. Carroll *et al.* (2022) addressed consumers' preferences for food bundling using a grocery shopping experiment with 250 consumers in America. They mentioned that food bundling can potentially increase profits in the grocery sector, especially for fresh products with lower profit margins. Regarding consumer preferences, they found that grocery bundling was preferred because consumers require less cognitive effort to process, which can benefit the consumers with the grocery shopping experience.

Alongside the bundling strategy as a tool to encourage or persuade consumers to buy more, understanding the buying criteria allows for examining the dynamics of a group of consumers. A hierarchy of purchase decisions can be designed to highlight the most important features to the buyers at the time of purchase. This view has increased profitability for manufacturers and related businesses (Nielsen, 2020). Understanding a hierarchical model of consumer behaviour for marketing communication activities is a foundation for changing consumer attitudes, especially behaviours that rely mainly on cognitive factors (Kim, 2018).

This study uses a nested logit (NL) choice model to measure consumer preferences for dairy products in a bundle. We grouped similar alternatives into nests and assumed a hierarchical decision-making structure (Ben-Akiva and Lerman, 1985). We asked consumers to select their products based on the proposed hierarchically structured decision tree. An algorithm based on the estimated parameters was then used to maximise the producer's revenue to suggest the optimal bundle, simultaneously considering consumer preference and the producer's or retailer's income.

Previous studies (Flores *et al.*, 2019; Raj *et al.*, 2023; Zhang *et al.*, 2023) developed and formulated optimisation algorithms using simulated data. In this study, as a contribution, we

apply the same algorithm to empirical (field) data collected through a consumer survey. In this way, the proposed theoretical algorithm is tested on empirical data. In this context, the research question is whether we can achieve the optimal bundle using the empirical data and the formulated optimisation algorithms.

Moreover, previous studies have examined the preferences of consumers and producers or sellers separately, whereas this study considers both aspects simultaneously. Integrating the simultaneous maximisation of consumer preferences and producer revenue (win-win strategy) can be a very useful and attractive marketing and sales strategy for retailers. Dairy suppliers can use this marketing strategy to promote sales and convince customers to use their specific dairy products. It can also be useful for policymakers and administrative decision-makers to promote public health (Sharpe and Staelin, 2010) and encourage the consumption of dairy products, for example, among vulnerable age groups such as children. According to this research contribution, the research question is whether the proposed final dairy bundle simultaneously addresses maximum consumer preference and maximum revenue for the producer. The remainder of the paper is organised as follows. In the next section, the research method is illustrated in detail. In the results section, the discrete choice model is estimated to examine consumers' dairy product preferences, and the final dairy product bundle is determined by the algorithm based on the estimated parameters. Finally, the results are discussed and compared with the results of other studies. In the last section, we draw our conclusions.

2. Materials and methods

2.1 Data collection

The data were collected in 2018 through a face-to-face survey questionnaire. The questionnaire consisted of three parts. The first part included personal characteristics such as age, gender, number of children, education, living expenses and other demographic characteristics of the respondents. The second part examined the respondent's level of awareness about the need to consume dairy products. In the third section, dairy consumption preferences were considered through questions regarding consumption and preference ratings for each dairy product, for example. Information on household demographic characteristics and the consumption of and preference for dairy products was also collected. The descriptive results of the variables are shown in Table 1.

The target population was in Sari, Iran. It was chosen because Mazandaran province is one of the top producers of dairy products in Iran (Jihadof, 2018), and Sari is the capital of the province (Figure 1).

The sample size of 285 was defined based on estimating the variance from 30 pilot pre-test questionnaires and using Cochran's sample size formula (Cochran, 1977). The respondents were selected based on convenience via a random mall-intercept method (Law, 2016). Finally, 275 valid questionnaires were completed out of 285 total respondents, with a response rate of 96%. We used the NLOGIT 5 software package (Greene, 2012) to estimate the model's parameters.

2.2 Behavioural model

Various models are used to investigate consumer behaviour and identify factors affecting consumer preferences. Choice modelling has proven useful in analysing and investigating consumers' behaviour and purchasing preferences, and it is widely used in marketing research (Louviere *et al.*, 2000). Discrete choice modelling (DCM) describes the behaviour of consumers when faced with a finite set of discrete options (McFadden, 1981; Kim, 2020). The multinomial logit (MNL) model is the workhorse statistical model in choice modelling

Independent variables	Percent of total	Independent variables	Percent of total
Age		*Occupational status*	
Young (20–34)	25	Unemployed	5
Middle (35–50)	28	Academic student	10
Adults (51–65)	26	Free job (private)	32
Old (>65)	21	Farmer	14
Gender		Employee (government)	39
Man	57	*Living cost*	
Woman	43	<500 thousand tomans	9
Household size		500th – 1 million T	24
1–2 members	24	1–2 million T	33
3–4 members	41	2–3 million T	23
5–6 members	28	>3 million T	11
More than 6 members	7	*Willingness to exercise*	
Education level		Very low	10
Illiterate	1.5	Low	24
Before diploma	9	Moderate	40
Diploma	23	High	21
Associate	18	Very high	5
Bachelor's	29		
Master's	12		
Doctoral	7.5		
Willingness to brand			
Low (1–3)	13		
Moderate (4–6)	40		
High (7–9)	47		

Source(s): Table by authors

Table 1.
Statistical description of the variables

Source(s): Figure by authors

Figure 1.
Location map of the case study

(Lancsar *et al.*, 2017). However, because the specific assumptions of MNL do not fit all the possible types of choice situations, researchers may need to use alternative and more flexible methods. The NL model, for instance, is a generalisation of the MNL model that relaxes a critical assumption of the basic logit models, namely, the independence of irrelevant alternatives (IIA) (Hensher *et al.*, 2015). Therefore, considering the potential of the NL model and its hierarchical structure, this model was used to estimate the factors affecting the choice of dairy products. The formulation of the model is as follows.

Let d denote a dairy product, and $P_{d|t}$ be the probability that product d is chosen by someone who decides to purchase a type of dairy product (denoted t). Suppose this probability is influenced by factors included in the vector x as independent variables. Under the usual MNL model, the choice of dairy products (d) conditional on the type of products is (Danaher and Dagger, 2012):

$$P_{d|t} = \frac{e^{\beta_d x_d}}{1 + \sum_{i=1}^{D} e^{\beta_{di} x_{di}}} \tag{1}$$

where d_i represents a range of 1–16 dairy products suggested to the consumers.

The probability of choosing a dairy product in the NL model is calculated as follows (Danaher and Dagger, 2012):

$$P_t = \frac{e^{\beta_d x_d + \eta I_v}}{1 + e^{\beta_d x_d + \eta I_v}} \tag{2}$$

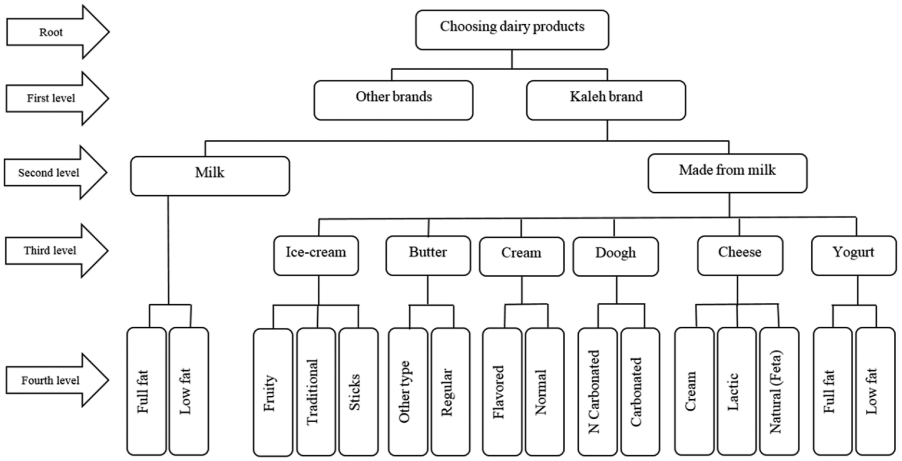
where I_v as an inclusive value indicates expected maximum utility and is defined as follows (Ben-Akiva and Lerman, 1985):

$$I_v = \log\left(1 + \sum_{i=1}^{D} e^{\beta_{di} x_{di}}\right) \tag{3}$$

and η is a dissimilarity parameter that can be considered a measure of the dissimilarity of alternatives or nests.

In the data collection tool, we considered demographic and socio-economic features such as age, gender, household size, education (based on seven levels of education degrees), occupational status (six levels), monthly family costs of living (five levels) as a proxy for disposable income, the level of importance of exercise to consumers (five-level semantic scale), consumer's awareness of the importance of consuming dairy products (three-level semantic scale), their preference for or tendency to purchase a particular brand of dairy products (rated with scores from 1 to 9) and consumers' price sensitivity.

Finally, we considered that brand choice and preference might be affected by the four classical marketing mix elements, based on the so-called four Ps of marketing: price (value), product (quality, packing, etc.), place (access to shopping) and promotion (loyalty, brand reputation and advertising). We asked the respondents about the importance of these elements using single-item direct questions. These factors can affect product choice separately or simultaneously (Astuti *et al.*, 2015). Consumers' dairy product choice process is described using a decision tree (Ahmadi Kaliji *et al.*, 2019). The tree has four levels corresponding to the 16 products in the fourth-level nodes (Figure 2). Based on this, consumers choose the brand of their dairy product at the first level; then, they determine the type of dairy products at the second and third levels. Finally, at the last level, they choose the final product in the related nest.



Source(s): Figure courtesy of Ahmadi Kaliji *et al.* (2019b)

Figure 2.
The suggested nested choice tree for dairy products

2.3 Technical algorithm

In line with the aim of the research, an iterative algorithm was used to maximise the producer's revenue by simultaneously considering the consumer's preference. In an iterative algorithm, a sequence of instructions is implemented, and the pre-defined steps are repeated until a stop-rule is met (Routh, 2016). In this study, we implement and illustrate the proposed algorithm using Microsoft Excel, executing the instructions manually without computer programming. However, these instructions and rules can easily be converted into a computer program using suitable software. After the calculations, the contents of the desired dairy bundle are suggested.

Once the NL model is estimated, the consumers' preference weight must be calculated at the beginning of the algorithm process. For this purpose, considering the proposed four-level decision tree (Figure 2), the attractiveness parameter (α_j) indicates the attractiveness of the dairy product corresponding to the node in level 4 (at this level, a node represents products derived from dairy products, such as low- or full-fat yoghurt, lactic-cream cheese).For the function of the offered bundle $B = (B_j : j \in V)$, a consumer associates the preference weight $w_{j(B_j)}$ with each node (dairy product). A consumer is more likely to purchase dairy products that have higher priority weights. The choice process starts from the root at the top of the nested choice tree until the consumer reaches a dairy product at the last level (fourth level), moving from top to bottom hierarchically. In particular, the probability of the following $k \in Children(j)$ node (dairy products presented in the fourth level) by a consumer in a non-leaf node (dairy products presented at the third level: yoghurt, cheese, doogh, cream, butter and ice cream; also to option at the second level: made from milk and directly from milk options; finally two option at the first level: Kaleh brand and other brands) j is $w_k(B_k)/\sum_{\ell \in Children(j)} w_\ell(B_\ell)$. Therefore, the preference weight for each non-leaf node (j) is computed as Li *et al.* (2015):

$$w_j(B_j) = \left(\sum_{k \in Children(j)} W_k(B_k) \right)^{\eta_j} \tag{4}$$

where η_j is a dissimilarity parameter from the NL model associated with node j. The parameter is reported in the final results of the estimation of the NL model.

In the next step of the algorithm, after calculating the weight corresponding to consumers' preferences, it is necessary to calculate the expected revenue from a consumer (corresponding to the aim of maximising the producer's revenue). Therefore, considering R_j as the expected revenue associated with the dairy product j, $R_j(B_j)$ is used to denote the expected revenue obtained from a consumer at node j (related dairy product and other options at other levels) in the tree during the choice process. If the consumer is at node j at the first, second and third levels, then he chooses the node $k \in Children(j)$ (dairy product on the next level, i.e. level four) with probability $w_k(B_k)/\sum_{\ell \in Children(j)} w_\ell(B_\ell)$. The expected revenue from a consumer is written at node j at the first, second or third levels (Li *et al.,* 2015):

$$R_j(B_j) = \sum_{k \in Children(j)} \frac{w_k(B_k)}{\sum_{\ell \in Children(j)} w_\ell(B_\ell)} \times R_k(B_k) = \frac{\sum_{k \in Children(j)} w_k(B_k) R_k(B_k)}{\sum_{k \in Children(j)} w_k(B_k)} \quad (5)$$

Therefore, we use the expected revenue associated with a dairy product and the attractiveness parameter or consumer preferences for each node or product on the fourth level or any related level. The estimated dissimilarity parameter is used to find the best dairy bundle based on consumer preferences for each option (node) at the second to fourth levels.

First, each dairy product's optimal solution as a bundle is the bundle with the highest expected revenue for the producer and is determined at the third level nodes (yoghurt, cheese, doogh, cream, butter and ice cream). For example, for yoghurt, the two recommended bundles can be determined (indicating the number of bundles that can only be offered with yoghurt, considering the maximum expected revenue). Then, we can verify that this collection includes an optimal solution for each dairy product. In the next step, to input the effect of consumers' preferences for each separate dairy product in the proposed bundle, the preference weight previously calculated based on equation (4) is multiplied by the expected revenue calculated based on equation (5).

The principle of the algorithm consists of drawing the lines that arise from the results of the last step – the lines with the slopes of $-W_{ji}(B_{j1})$, $-W_{j2}(B_{j2})$, and y-intercepts of $w_{j1}(B_{j1})R_{j1}(B_{j1})$, $w_{j2}(B_{j2})R_{j2}(B_{j2})$ (Figure 3). For this problem, if the suggested dairy product bundle is $B_j = \{\{j_1, j_2\}, \{j_2\}, \varphi\}$, and j_1 and j_2 are derivatives of the j dairy product, we can verify that this collection includes an optimal solution at the j dairy product node in the suggested tree. Each subset was constructed based on the maximum expected revenue. Each

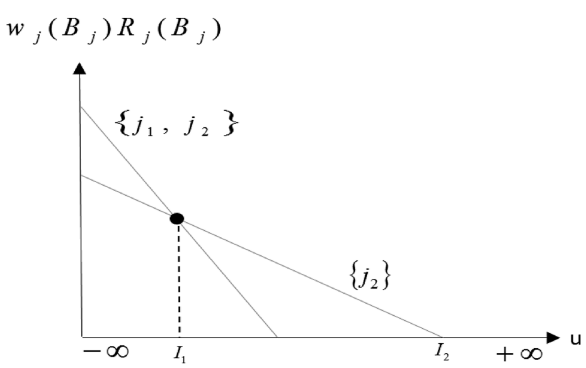


Figure 3.
The lines and points for j product collection

Source(s): Figure by authors

node's preference weight and expected revenue in the third level were calculated using equations (4) and (5), respectively. Each product's expected revenue was calculated based on a standardised 100 grams quantity to homogenise the dairy products. Finding the pairwise intersection points (optimal intervals or solutions) of these two lines, if the interval is $[-\infty, I_1]$, then the highest of these lines corresponds to the dairy product subset $\{j_1, j_2\}$. Similarly, if the interval is $[I_1, I_2]$, the highest line corresponds to the dairy product subset $\{j_2\}$. The calculation formats are the same for the other dairy products.

In the next step, the optimal bundle proposed for each dairy product is checked together with other dairy products to provide a combined bundle of all dairy products. A similar algorithm is repeated until the upper levels of the decision tree (towards the root) are reached.

Since we assume that each consumer starts the choice process from the root (top of the tree), if bundle B is offered, then the expected revenue obtained from a consumer is $R_{root}(B_{root})$. This study aims to find a bundle that maximises the expected revenue from a consumer at the root. The objective function to be maximised is the following (Li *et al.*, 2015).

$$Z = \max_{B \subseteq \{1,\ldots,n\}} R_{root}(B_{root}) \tag{6}$$

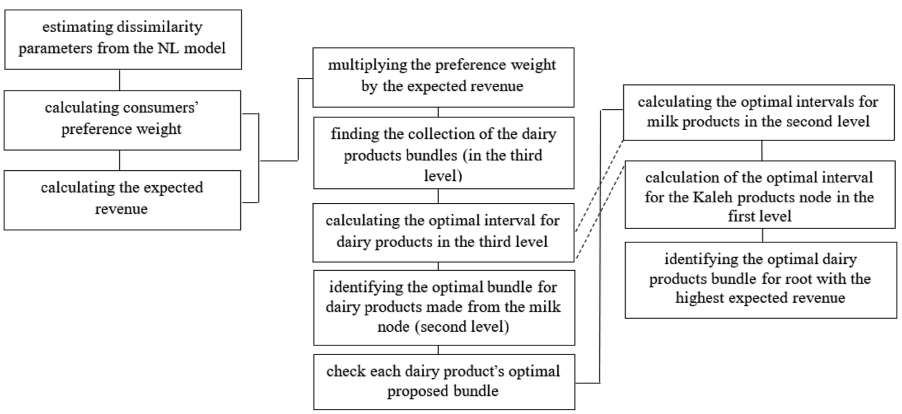
Therefore, the algorithm can be summarised as shown in Figure 4.

This algorithm was discussed theoretically in previous studies; in this study, we also perform the calculations and discuss practical aspects and results. The algorithm's output is obtained through numerical calculations with widely used spreadsheet software, Microsoft Excel, to provide an empirical example. A final dairy bundle with the highest expected revenue, considering consumer preferences, is selected after consecutive calculations, as illustrated in the results section.

3. Results

3.1 The estimated nested logit model

The NL model was used to estimate the factors affecting the choice and preference of dairy products. According to the hierarchical decision-making approach, the purchasing decision process is like a decision tree. The choice of the nest and dairy products depends on the factors discussed in the following text.



Source(s): Figure by authors

Figure 4.
Diagram of conducting the algorithm

The results of the Hausman test (Hausman and McFadden, 1984) were examined to verify the need for the NL model. If the assumption of independence of IIA is violated, using more advanced logit models, including the NL model is justified. Indeed, the Hausman test statistics (chi-square coefficient:17.54, significant at the 1% level) shows that the IIA assumption was violated.

The results of the NL model estimation are reported in Table 2. The analysis of associations with demographic characteristics revealed that consumers' age had a positive and statistically significant effect on choosing products such as low-fat milk and yoghurt, non-carbonated doogh and regular butter. It had the most substantial effect on milk choice, which indicates that older consumers tend to consume low-fat dairy products because of conditions like high blood cholesterol. Consumers' sensitivity to consuming low- or full-fat products can also be seen as a result of the exercise variable's significant effect on the probability of choosing low-fat milk. The level of education can also affect the choice of healthy and low-fat dairy products. Men preferred less full-fat yoghurt, cream cheese and sticks ice cream. Greater household size increased the probability of choosing various products, such as ice cream types. Brand preferences affect the probability of choosing full-fat yoghurt, lactic cheese and sticks ice cream. The four classical marketing mix elements also influenced consumers' preferences. Price (4p), product (4p), place (4p) and promotion (4p) had the strongest effect on the probability of choosing cream cheese, non-carbonated doogh, traditional ice cream and cream cheese products, respectively. This outcome may be because of product value, quality, packing, shopping access, brand loyalty and reputation.

3.2 Optimisation algorithm

To run the optimisation algorithm, we need the estimated coefficients of inclusive value (as dissimilarity parameters) in Table 3 to calculate each dairy product node's preference weight (equation 4). These coefficients also confirm the nests' independence based on Figure 2 (Hauber and Parsons, 2000; Wen, 2010).

We used the parameters R_j (expected revenue associated with dairy product j) and α_j (attractiveness parameter or consumer preferences) for each node or dairy product in the fourth level, and the estimated η_j (dissimilarity parameter) for each node on the second to fourth levels (coefficients in Table 3), to find the best dairy bundle based on consumer preferences (The abbreviations of the names of dairy products are listed in Appendix, Table A1).

First, each dairy product's optimal interval/solution was calculated on the third level (yoghurt, cheese, doogh, cream, butter and ice cream). For this problem if $B_y = \{\{ylf, yff\}, \{ylf\}, \varphi\}$ (the number of bundles that can only be offered with yoghurt, considering maximum expected revenue), then we can verify that this collection includes an optimal solution at the yoghurt node. Similarly, if $B_{ch} = \{\{chn, chl, chc\}, \{chl, chc\}, \{chc\}, \varphi\}$, then this collection includes an optimum at the cheese product (node). Each subset of this collection was constructed based on the maximum expected revenue. The preference weight and expected revenue of each dairy product node on the third level were calculated using equations (4) and (5), respectively. Each product's expected revenue was calculated based on a standardised 100 grams quantity to homogenise the dairy products. The preference weight results are shown in the second row of Table A2. These were multiplied by the expected revenue calculated based on equation (5), and the results are presented in the third row of Table A2. To find the optimal interval/solution in this table's fourth row, consider the lines with the slope $-w_y(B_y)$ and y-intercept $w_y(B_y)R_y(B_y)$, where $w_y(B_y)$ is calculated based on equation (4). Finding the pairwise intersection points of these two lines, if the interval is $[-\infty, 577]$, the highest of these lines corresponds to the subset $\{ylf, yff\}$.

Variables	Products	Coefficient	Standard deviation	Z	Marginal effect (per cent)
Price	Total products	−1.417***	0.593	−2.39	−0.308
Age	Low-fat milk	5.655***	2.077	2.72	1.230
	Low-fat yoghurt	1.261***	0.512	2.47	0.274
	N-carbonated doogh	0.456***	0.201	2.27	0.099
	Regular butter	4.062*	2.284	1.78	0.883
Gender	Full-fat yoghurt	−4.249*	2.365	−1.80	−0.924
	Cream cheese	−1.431***	0.555	−2.58	−0.311
	Normal cream	0.965**	0.505	1.91	0.210
	Other butter	4.026*	2.264	1.78	0.876
	Sticks ice cream	−6.408*	3.784	−1.69	−1.394
Household size	Low-fat milk	1.254***	0.323	3.88	0.273
	Natural cheese	5.111***	1.762	2.90	1.112
	N-carbonated doogh	3.132**	1.448	2.16	0.681
	Traditional ice cream	2.413***	1.003	2.40	0.525
	Fruity ice cream	7.043*	4.032	1.75	1.532
Education	Low-fat milk	0.482**	0.247	1.96	0.105
	Low-fat yoghurt	0.927*	0.550	1.69	0.202
	N-carbonated doogh	0.792*	0.462	1.72	0.172
	Regular butter	2.644***	0.786	3.36	0.575
	Traditional ice cream	1.753***	0.768	2.28	0.381
Living cost	Low-fat yoghurt	−1.244*	0.715	−1.74	−0.271
	Natural cheese	4.812***	1.549	3.11	1.047
	Lactic cheese	−3.664***	1.005	−3.64	−0.797
	Normal cream	−3.212***	1.436	−2.24	−0.699
	Sticks ice cream	−0.782*	0.428	−1.83	−0.170
Exercise	Low-fat milk	1.226***	0.247	4.97	0.267
Brand	Full-fat yoghurt	1.620*	0.881	1.84	0.352
	Lactic cheese	1.729***	0.518	3.34	0.376
	Sticks ice cream	1.335*	0.260	5.12	0.290
Price (4p)	Full-fat yoghurt	1.965**	0.918	2.14	0.427
	Natural cheese	2.052**	0.989	2.07	0.446
	Cream cheese	−4.061***	1.276	3.18	−0.883
	Normal cream	−1.846**	0.884	−2.09	−0.401
	Regular butter	0.751*	0.414	1.81	0.163
	Sticks ice cream	0.246***	0.076	3.26	0.053
	Traditional ice cream	0.761***	0.347	2.19	0.165
	Fruity ice cream	−3.075***	1.246	−2.47	−0.669
Product (4p)	Low-fat milk	1.326*	0.789	1.68	0.288
	Full-fat yoghurt	1.768*	1.004	1.76	0.384
	N-carbonated doogh	2.165**	1.027	2.11	0.471
	Regular butter	−1.433*	0.764	−1.87	−0.312
Place (4p)	Traditional ice cream	2.009*	1.138	1.77	0.437
Promotion (4p)	Cream cheese	1.746**	0.884	1.97	0.380

Note(s): ***, ** and * indicate significance at the 1, 5 and 10% levels, respectively
McFadden pseudo $R^2 = 0.58$, chi-squared = 7.44, log-likelihood function = −26.31
Source(s): Table by authors

Table 2.
Nested logit model estimation results

Table 3.
Estimation results of inclusive value coefficient

	Nest	Coefficient	Standard deviation	Z statistics
Second level	Yoghurt	0.852***	0.261	3.26
	Cheese	0.678***	0.279	2.43
	Doogh	0.468**	0.242	1.93
	Cream	0.497***	0.224	2.22
	Butter	0.503*	0.279	1.80
	Ice cream	0.566*	0.324	1.75
Third level	Milk products	1.428*	0.87	1.64
	Milk final consumption	0.712**	0.368	1.94
Fourth level	Company brand	2.154***	0.923	2.33
	Other brand	1.514***	0.722	2.10

Note(s): ***, ** and * indicate significance at the 1, 5 and 10% levels, respectively
Source(s): Table by authors

Similarly, if the interval is [577,710], then the highest line corresponds to the subset $\{ylf\}$. In other words, if the interval is $[-\infty, 577]$, then the optimal solution is given by $\{ylf, yff\}$. Thus, the points are given by $\{-\infty, 577, 710, +\infty\}$. We then considered the lines with the slope -27.7 and y-intercept 17,697, and the slope -13.9 and y-intercept 9,869. Thus, the intersection point between two lines for yoghurt bundles is 577. We performed these calculations similarly for yoghurt, cheese, doogh, cream, butter, ice cream and milk (Table A2).

Taking the union of these interval points in Table A2, 15 intervals in Table A3 were obtained to identify optimal bundles for products in the milk node (second level). In this case, if the interval is $[-\infty, 92]$, the optimal bundle for this interval is {ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, ik, it, if}, which includes total products made from milk (except final milk products because there are none on the third level). Similarly, if the interval is [92, 264], the optimal bundle is {low-fat yoghurt, full-fat yoghurt, normal cheese, lactic cheese, cream cheese, carbonated doogh, non-carbonated doogh, normal cream, flavored cream, regular butter, other-type butter, traditional ice cream and fruity ice cream}, from which sticks ice cream (IS) are excluded.

Based on the last algorithm (Tables A2 and A3), optimal intervals were calculated for milk products on the second level. The first interval calculated $[-\infty,189]$ with a bundle of {ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if}. Since the Kaleh brand had the highest preference over other brands of dairy products, these results were used with the optimal interval result of milk {mlf, mff}, and {mlf} to identify the optimal bundle for the Kaleh products node on the first level (Table A5). In the first interval of Table A4 ($[-\infty,189]$), the bundle is {ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if, mlf, mff}. This bundle includes the whole assortment of dairy products the Kaleh company offers.

There are two nodes on the first level (Kaleh brand and other brands), and optimal intervals were calculated based on Table A6 and consumers' preferences regarding other brands. The results are shown in Table A7.

After solving the optimisation problem, the dairy products collection with the highest expected revenue includes an optimal bundle, and the result for the root is shown in Table A7. Therefore, the optimal bundle is {ylf, chc, bo} **(low-fat yoghurt, cream cheese, other-type butter)** with an expected revenue of 1910 tomans (which is a super unit of the official currency of Iran, the rial) equal to 0.50 euro, considering that each product's expected revenue was calculated based on a standardised 100 grams quantity to homogenise the dairy products.

4. Discussion

We analysed consumers' preferences using the NL model as a hierarchical decision model. Hierarchical analysis of product selection can be a dynamic solution for highlighting

shopping attributes. Analysing factors affecting consumer preferences revealed that demographic characteristics and marketing mix elements affected consumers' preferences. Consistent with previous research (Bhanu *et al.*, 2017; Kaguru *et al.*, 2017) and the economic theory, price increases decreased choice probability. However, consumers are willing to pay a premium for dairy products if they perceive them to be higher quality or more nutritious (Habiyaremye *et al.*, 2023; McGuinness *et al.*, 2022). In addition, various pricing strategies, such as bundle offers, discounts or value packages, can attract price-sensitive consumers and encourage larger purchases (Bimbo *et al.*, 2016; Zhou *et al.*, 2023).

The results concerning the age variable showed that older people and people concerned about their health tended to consume low-fat dairy products. This finding is in line with the studies of Hamilton *et al.* (2000), Kähkönen (2000) and Johnston *et al.* (2014), who claim that older adults and people who are concerned about their health tend to eat low-fat foods due to various reasons related to nutrition and health benefits. The tendency of consumers to choose low-fat milk is consistent with the findings of Küster and Vila (2017), who found that the concepts of health and appearance play an important role in people's attitudes towards consuming low-fat products.

As previous research confirms, household size increases the probability of choosing various products, especially in developing countries where household size can vary more and be much larger than in developed countries (Nie and Zepeda, 2011; Verzeletti *et al.*, 2010; Yeo *et al.*, 2020). Larger households usually have more people to feed, which often results in a higher total consumption of dairy products. This higher consumption may include larger amounts of milk, yoghurt, cheese and other dairy products.

The classical marketing mix elements, that is product value, quality, packaging, access to shopping and brand loyalty, also affect consumers' preferences. This result echoes the finding of Ahmadi Kaliji *et al.* (2019), Nguyen *et al.* (2015) and Wongleedee (2015). Quality is a critical factor in consumer choice. To earn consumer trust, dairy products must meet certain standards for taste, consistency and freshness (Sajdakowska *et al.*, 2020). Products that are of consistently high quality are more likely to win consumer loyalty and receive positive word of mouth (Kim, 2021). In addition, packaging plays an important role in attracting consumer attention and conveying information about the product. Attractive and informative packaging can set a product apart from its competitors, convey important features and evoke positive emotions (Shukla *et al.*, 2022). Furthermore, in the case of access to shopping, convenient access to dairy products influences consumer preferences (Bahety *et al.*, 2022; Canavari *et al.*, 2019). Convenience stores, supermarkets and online marketplaces that carry a wide variety of dairy products meet a wide range of consumer needs and preferences.

Regarding the best bundle of dairy products, a bundle containing low-fat yoghurt, cream cheese and other butter types was presented with the highest expected revenue. The bundle's contents can be modified based on the company's goals and consumers' preferences. This sales method can promote the consumption and sale of dairy products and, more generally, fresh foods. Targeted dairy bundles can be proposed for segments with specific needs and desires, such as a "low-fat dairy bundle" for elderly consumers or a "diet dairy bundle" for athletes or people who want to lose weight (Li *et al.* (2018).

5. Conclusions

This paper proposed an approach to suggest a dairy product bundle that maximises both consumer utility and producer revenue. According to the results, demographic characteristics and marketing mix elements significantly influenced consumer preferences. In addition, regarding the best bundle of dairy products, an algorithm based on the estimated dissimilarity parameter identified the best bundle of dairy products that simultaneously achieves the highest utility and expected revenue.

5.1 Theoretical implications

This study applies a bundling strategy to the food market, which has received little attention in previous research despite the wide use of bundling in practice. Previous studies have addressed the benefits of bundling for producers and marketers, including launching a new brand (Sheng and Pan, 2009), gaining consumer surplus (Venkatesh and Mahajan, 2009) and differentiating service and product offerings (Dominique-Ferreira, 2017). In contrast to these previous applications, in addition to the usual approach of maximising producer revenue, we also consider consumer preferences when selecting and designing the bundled content. The bundled content is determined using a hierarchical structure-based choice model that extends the bundled content selection methods proposed by Li *et al.* (2015).

5.2 Managerial and policy implications

Maximising consumer preferences and producer revenues can be a useful and attractive marketing and retail management strategy. Studying consumer responses to different types of bundle offers can help companies understand what motivates customers to make bundle purchases and what factors influence their decisions. Dairy product suppliers can use this marketing strategy to increase sales and convince customers to use their specific dairy products.

Research on product bundling can contribute to pricing strategies in various industries. Studying the impact of different bundling approaches on pricing and profitability can help companies optimise their pricing models to maximise revenue. The results of our study show that in addition to price, perceptions of quality, brand and advertising influence the choice of bundled content. Therefore, managers and marketers can pay special attention to these factors and adjust bundle content to meet customers' needs and promote their brand.

5.3 Limitations and opportunities for future research

This study has limitations that can be addressed in future research. The survey was conducted in a developing country, and its results should be validated in other contexts. In addition, the dairy preference data used in this study were collected in 2018, following the introduction of an increasing number and variety of dairy products into that market. Future studies should examine the effect of the latter on consumer preferences.

In terms of methodology, we examined the dairy decision tree at four levels, but more (or fewer) levels in the NL model might be appropriate in different situations. Finally, in our model, there was only one unit of each dairy product in the proposed bundle. In addition to considering the role of preferences in choosing a multi-product bundle, consumption habits can be incorporated into the model by allowing more than one unit of each dairy product type in each bundle.

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Appendix

Dairy products	Name	Dairy products	Name
Low-fat yoghurt	ylf	Flavoured cream	Cf
Full-fat yoghurt	yff	Regular butter	Br
Normal cheese	chn	Other types of butter	Bo
Lactic cheese	chl	Sticks ice cream	Is
Cream cheese	chc	Traditional ice cream	It
Carbonated doogh	dc	Fruity ice cream	If
Non-carbonated doogh	dn	Low-fat milk	Mlf
Normal cream	cn	Full-fat milk	Mff

Source(s): Table by authors

Table A1. The abbreviations of the names of dairy products

B_y (Bundle for yoghurt products)	$\{ylf, yff\}$	$\{ylf\}$	φ	
$W_y(B_y)$	27.7	13.9	0	
$W_y(B_y)R_y(B_y)$	17,697	9,869	0	
Optimal interval	$[-\infty, 577]$	[577,710]	$[710, +\infty]$	
B_{ch}	$\{chn, chl, chc\}$	$\{chl, chc\}$	$\{chc\}$	φ
$W_{ch}(B_{ch})$	14	9.9	7.3	0
$W_{ch}(B_{ch})R_{ch}(B_{ch})$	9,709	7,219	5,475	0
Optimal interval	$[-\infty, 607]$	[607,671]	[671,750]	$[750, +\infty]$
B_d	$\{dc, dn\}$	$\{dn\}$	φ	
$W_d(B_d)$	7.1	5.3	0	
$W_d(B_d)R_d(B_d)$	2,331	1855	0	
Optimal interval	$[-\infty, 264]$	[264,350]	$[350, +\infty]$	
B_c	$\{cn, cf\}$	$\{cf\}$	φ	
$w_c(B_c)$	3.3	2.2	0	
$w_c(B_c)R_c(B_c)$	2039	1,430	0	
Optimal interval	$[-\infty, 554]$	[554,650]	$[650, +\infty]$	
B_b	$\{br, bo\}$	$\{bo\}$	φ	
$w_b(B_b)$	4.4	2.6	0	
$w_b(B_b)R_b(B_b)$	2,760	1820	0	
Optimal interval	$[-\infty, 522]$	[522,700]	$[700, +\infty]$	
B_i	$\{is, it, if\}$	$\{it, if\}$	$\{if\}$	φ
$w_i(B_i)$	6.6	5	3.2	0
$w_i(B_i)R_i(B_i)$	2,852	2,704	1920	0
Optimal interval	$[-\infty, 92]$	[92,436]	[436,600]	$[600, +\infty]$
B_m	$\{mlf, mff\}$	$\{mlf\}$	φ	
$w_m(B_m)$	16.7	8.9	0	
$w_m(B_m)R_m(B_m)$	6,994	4,005	0	
Optimal interval	$[-\infty, 383]$	[383,450]	$[450, +\infty]$	

Source(s): Table by authors

Table A2. Calculation of the optimal interval for dairy products in the third level

Interval	[−∞, 92]	[92,264]
Bundle	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if}	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, it, if}
Interval	[264,350]	[350,436]
Bundle	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if}	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if}
Interval	[436,522]	[522,554]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, if}	{ylf, yff, chn, chl, chc, cn, cf, bo, if}
Interval	[554,577]	[577,600]
Bundle	{ylf, yff, chn, chl, chc, cf, bo, if}	{ ylf, chn, chl, chc, cf, bo, if}
Interval	[600,607]	[607,650]
Bundle	{ ylf, chn, chl, chc, cf, bo}	{ ylf, chl, chc, cf, bo}
Interval	[650,671]	[671,700]
Bundle	{ ylf, chl, chc, bo}	{ ylf, chc, bo}
Interval	[700,710]	[710,750]
Bundle	{ ylf, chc }	{chc }
Interval	[750, +∞]	
Bundle	φ	

Source(s): Table by authors

Table A3. Identifying the optimal bundle for products made from milk node (second level)

Bundle	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if}	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, it, if}
$w_{mp}(B_{mp})$	160	155
$w_{mp}(B_{mp})$	94,803	93,857
$R_{mp}(B_{mp})$		
Optimal interval	[−∞,189]	[189,297]
Bundle	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if}	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if}
$w_{mp}(B_{mp})$	150	137
$w_{mp}(B_{mp})$	92,372	85,989
$R_{mp}(B_{mp})$		
Optimal interval	[297,399]	[399,485]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, if}	{ylf, yff, chn, chl, chc, cn, cf, bo, if}
$w_{mp}(B_{mp})$	129	123
$w_{mp}(B_{mp})$	83,532	80,192
$R_{mp}(B_{mp})$		
Optimal interval	[485,557]	[557,565]
Bundle	{ylf, yff, chn, chl, chc, cf, bo, if}	{ylf, chn, chl, chc, cf, bo, if}
$w_{mp}(B_{mp})$	120	81
$w_{mp}(B_{mp})$	78,496	55,370
$R_{mp}(B_{mp})$		
Optimal interval	[565,593]	[593,618]
Bundle	{ylf, chn, chl, chc, cf, bo}	{ylf, chl, chc, cf, bo}

(*continued*)

Table A4. Calculation optimal interval for products made from milk node (second level)

Bundle	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if}	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, it, if}
$w_{mp}(B_{mp})$	72	61
$w_{mp}(B_{mp})$	49,805	43,082
$R_{mp}(B_{mp})$		
Optimal interval	[618,624]	[624,663]
Bundle	{ylf, chl, chc, bo}	{ylf, chc, bo}
$w_{mp}(B_{mp})$	55	49
$w_{mp}(B_{mp})$	39,102	35,051
$R_{mp}(B_{mp})$		
Optimal interval	[663,675]	[675,681]
Bundle	{ylf, chc}	{chc}
$w_{mp}(B_{mp})$	42	11
$w_{mp}(B_{mp})$	29,946	7,150
$R_{mp}(B_{mp})$		
Optimal interval	[681,697]	[697,715]
Bundle	φ	
$w_{mp}(B_{mp})$	0	
$w_{mp}(B_{mp})$	0	
$R_{mp}(B_{mp})$		
Optimal interval	[715, $+\infty$]	

Source(s): Table by authors

Table A4.

Interval	[$-\infty$,189]	[189,297]
Bundle	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if, mlf, mff}	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, it, if, mlf, mff}
Interval	[297,383]	[383,399]
Bundle	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if, mlf, mff}	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if, mff}
Interval	[399,450]	[450,485]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if, mff}	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if}
Interval	[485,557]	[557,565]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, if}	{ylf, yff, chn, chl, chc, cn, cf, bo, if}
Interval	[565,593]	[593,618]
Bundle	{ylf, yff, chn, chl, chc, cf, bo, if}	{ylf, chn, chl, chc, cf, bo, if}
Interval	[618,624]	[624,663]
Bundle	{ylf, chn, chl, chc, cf, bo}	{ylf, chl, chc, cf, bo }
Interval	[663,675]	[675,681]
Bundle	{ylf, chl, chc, bo}	{ylf, chc, bo}
Interval	[681,697]	[697,715]
Bundle	{ylf, chc}	{chc}
Interval	[715, $+\infty$]	–
Bundle	φ	–

Source(s): Table by authors

Table A5.
Identifying the optimal bundle for Kaleh products node (first level)

Bundle	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if, mlf, mff}	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, it, if, mlf, mff}
$w_k(B_k)$	4,797	4,577
$w_k(B_k)$ $R_k(B_k)$	3,864,502	3,848,910
Optimal interval	[−∞, 71]	[71,104]
Bundle	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if, mlf, mff}	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if, mff}
$w_k(B_k)$	4,360	4,031
$w_k(B_k)$ $R_k(B_k)$	3,826,280	3,780,536
Optimal interval	[104,112]	[112,117]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if, mff}	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if}
$w_k(B_k)$	3,450	3,049
$w_k(B_k)$ $R_k(B_k)$	3,738,428	3,689,907
Optimal interval	[117,121]	[121,125]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, if}	{ylf, yff, chn, chl, chc, cn, cf, bo, if}
$w_k(B_k)$	2,865	2,650
$w_k(B_k)$ $R_k(B_k)$	3,612,907	3,611,950
Optimal interval	[125,127]	[127,141]
Bundle	{ylf, yff, chn, chl, chc, cf, bo, if}	{ylf, chn, chl, chc, cf, bo, if}
$w_k(B_k)$	2,545	1,337
$w_k(B_k)$ $R_k(B_k)$	3,532,460	1,911,910
Optimal interval	[141,176]	[176,247]
Bundle	{ylf, chn, chl, chc, cf, bo}	{ylf, chl, chc, cf, bo}
$w_k(B_k)$	1,102	840
$w_k(B_k)$ $R_k(B_k)$	1,700,386	1,389,360
Optimal interval	[247,276]	[276,352]
Bundle	{ylf, chl, chc, bo}	{ylf, chc, bo}
$w_k(B_k)$	709	587
$w_k(B_k)$ $R_k(B_k)$	1,233,660	1,085,950
Optimal interval	[352,418]	[418,468]
Bundle	{ylf, chc }	{ chc }
$w_k(B_k)$	456	51
$w_k(B_k)$ $R_k(B_k)$	533,520	34,833
Optimal interval	[468,542]	[542,683]
Bundle	φ	
$w_k(B_k)$	0	
$w_k(B_k)$ $R_k(B_k)$	0	
Optimal interval	[683, +∞]	

Source(s): Table by authors

Table A6.
Calculation optimal interval for Kaleh products node (first level)

Interval	$[-\infty,71]$	[71,104]
Bundle	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, is, it, if, mlf, mff}	{ylf, yff, chn, chl, chc, dc, dn, cn, cf, br, bo, it, if, mlf, mff}
Expected price	786	840
Interval	[104,112]	[112,117]
Bundle	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if, mlf, mff}	{ylf, yff, chn, chl, chc, dn, cn, cf, br, bo, it, if, mff}
Expected price	896	984
Interval	[117,121]	[121,125]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if, mff}	{ylf, yff, chn, chl, chc, cn, cf, br, bo, it, if}
Expected price	1,231	1,264
Interval	[125,127]	[127,141]
Bundle	{ylf, yff, chn, chl, chc, cn, cf, br, bo, if}	{ylf, yff, chn, chl, chc, cn, cf, bo, if}
Expected price	1,370	1,328
Interval	[141,176]	[176,247]
Bundle	{ylf, yff, chn, chl, chc, cf, bo, if}	{ylf, chn, chl, chc, cf, bo, if}
Expected price	1,405	1,466
Interval	[247,276]	[276,352]
Bundle	{ylf, chn, chl, chc, cf, bo }	{ylf, chl, chc, cf, bo }
Expected price	1,520	1,684
Interval	[352,418]	[418,468]
Bundle	{ylf, chl, chc, bo }	{ylf, chc, bo }
Expected price	1,752	1,910
Interval	[468,542]	[542,683]
Bundle	{ylf, chc }	{ chc }
Expected price	1,260	690
Interval	$[683, +\infty]$	–
Bundle	φ	–
Expected price	0	

Source(s): Table by authors

Table A7.
Identifying the optimal bundle for root

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Lack of resilience after COVID-19: the role of family firm heterogeneity and behavior. fsQCA versus regression

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Abstract

Purpose – This study analyzes antecedents explaining the lack of resilience in family-owned firms. Our model suggests that family-owned firms' strategic behaviors and heterogeneity explain a particular crisis outcome: a lack of recovery.

Design/methodology/approach – Our evidence is based on a sample of 842 European family-owned firms. We complement regression analysis results with fuzzy-set qualitative comparative analysis (fsQCA).

Findings – Our results show that lack of resilience is relevant. In fact, in our sample, 60% of family firms (FFs) failed to recover their sales. This evidence supports the role played by exploitation and exploration behavior as well as family heterogeneity in explaining the lack of recovery.

Research limitations/implications – Our results may offer guidance to practitioners and policymakers on the pathways that explain the lack of resilience.

Practical implications – Although it is unlikely that an external crisis such as COVID-19 will occur again to the same extent, other threatening events may occur and impact FFs. Understanding how FFs can avoid non-recovery is crucial: it can inform managers on how to deal with stressful events and provide guidance to economic authorities on how to help FFs around the world avoid non-recovery, which affects the economy.

Originality/value – First, the study contributes to FF research by offering a theoretical explanation for the different effects of FF attributes on non-recovery in the context of a global crisis. Second, it contributes to the literature on organizational resilience by examining explorative and exploitative behaviors as antecedents of FF non-recovery. Third, we show the usefulness of combining fsQCA and regression analysis to understand complex phenomena.

Keywords Resilience, Exploration, Exploitation, Recovery, Family firm

Paper type Research paper

1. Introduction

Family firms (FFs) account for much of the world economy and are subject to stressful disruptions, abrupt changes and extreme events during their lives. Importantly, some of

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these events are external and worldwide, such as the COVID-19 or the global financial crisis (GFC) and have drawn the attention of strategic research to firms that recover and are able to bounce back to their pre-event state (i.e. achieve resilience outcomes, Linnenluecke, 2017; Williams *et al.*, 2017). Thus, recent studies have focused on FFs' responses to these threats (Amore *et al.*, 2022; Rivo-López *et al.*, 2020), attempting to clarify which FFs can resist these events.

However, during these worldwide crises, although some FFs demonstrated resilience outcomes (i.e., survival and recovery), many did not recover. In fact, three years after the GFC, European manufacturing firms had not recovered their turnover figures (EUROSTAT, 2022). In the case of FFs and COVID-19, 64% of European FFs had not recovered their revenue in October 2020 (KPMG, 2021). Thus, these global and distressful crises provide acute challenges for FFs. Therefore, managers, society and policymakers will benefit from a better understanding of what explains FFs' inability to rebound after these worldwide events (Campopiano *et al.*, 2019).

To answer this question, we follow a line of research that argues that, from a strategic level of analysis of resilience outcomes, post-crisis recovery may be influenced by two core elements: the organization's characteristics and its strategic behavior during the crisis (Conz and Magnani, 2020; Hillmann and Guenther, 2020).

First, we argue that a firm's strategic behavior must address the opportunities and threats arising from these global crises in order to recover from them. On the one hand, in order to reduce costs, a firm may choose to engage in exploitative behavior by downsizing its workforce, increasing productivity, or cutting unnecessary costs. On the other hand, it can focus on generating additional income from new and diverse sources through exploration-oriented behavior (Schmitt *et al.*, 2010; Dolz *et al.*, 2019). Thus, firms must make crucial decisions that entail exploitation behaviors, such as cutting operating costs, divesting key assets, workforce or wage reductions (McGuinness *et al.*, 2018; Rivo-López *et al.*, 2020). Additionally, as new opportunities emerge, some firms may take extraordinary risks and engage in high levels of exploration (Leppäaho and Ritala, 2022; Mahto *et al.*, 2022). While firms are exposed throughout their life to internal and external crises that undermine their stability, global crises such as the recent pandemic may give them a chance to do what once seemed unimaginable (Wenzel *et al.*, 2020). For example, in terms of exploitation behaviors, changes in regulations and state contingency measures may allow actions that were unthinkable before the crisis; or in terms of exploration, as occurred regarding the physical and online distribution channels, the lockdown made some distribution channels obsolete, which called for new ones (Parida *et al.*, 2016). Recent research highlights that FFs change their usual strategic behaviors when faced with threatening events, including exploitative behavior through labor cost reduction (KPMG, 2021), or explorative behavior and a risk-taking approach at such a time (Leppäaho and Ritala, 2022). We argue that both strategic behaviors may affect the likelihood of FFs' non-recovery.

Second, as for organizational attributes, we argue that specific FF characteristics can be crucial for decision-making when dealing with a stressful global external event. We claim that these extraordinary events bring FFs' financial and emotional goals to the fore (Chua *et al.*, 2018) since non-recovery will put them at stake. However, FFs are heterogeneous and, as such, may handle extraordinary events differently, as indicated by Calabrò *et al.* (2021), Le Breton-Miller and Miller (2022) and Zahra (2022) for the COVID-19 pandemic. Thus, following researchers who state that FFs vary in terms of family involvement in ownership, management, the generation in control (GC), or size (Arteaga and Escribá-Esteve, 2021), we argue that these attributes may help explain the likelihood of non-recovery since they affect FFs' likelihood of achieving their financial and emotional goals.

To explain this complex phenomenon of non-recovery in extreme circumstances through FF strategic behaviors and heterogeneous attributes, we examined a sample of 842 European

FFs surveyed by affiliates of the well-established *Successful Transgenerational Entrepreneurship Practices* (STEP) project as part of a study completed in October 2020. We rely on classical regression models and complement them with fuzzy-set qualitative comparative analysis (fsQCA). fsQCA is a novel qualitative method that uses qualitative inquiry with quantitative exploration through configurational analysis to understand complex phenomena and has been applied to the FF phenomena (Calabrò *et al.*, 2022b). This methodology allows researchers to uncover and explain contrarian cases relevant to the research question. As Gligor and Bozkurt (2020) note, the "all-or-nothing" relationship covered by regression analyses can be supplemented with the fsQCA methodology.

2. Literature review and hypotheses development

2.1 Firm resilience

In the last decades, firms have been dealing with an increased number of unexpected and extreme events, e.g. the GFC, the COVID-19 pandemic and the Russo–Ukrainian war. How to deal with these unexpected events that undermine the stability and security of an organization (Annarelli and Nonino, 2016) demands considerable attention from both academicians and managers. One fruitful line sheds light on which capabilities allow firms to achieve resilience outcomes (Annarelli and Nonino, 2016; Iborra *et al.*, 2020, 2022). However, the lack of recovery –a widespread outcome of firms' vulnerability/non-resilience after these crises– calls for additional research.

The literature on FFs has tried to answer if FFs outperform non-family ones in terms of resilience after global crises. Evidence for 2008s GFC has been inconclusive: some studies indicate that FFs do better than non-family ones (Minichilli *et al.*, 2016), while others show the opposite (Lins *et al.*, 2013). Concerning the COVID crisis, a recent study highlighted that FFs outperform non-family ones (KPMG, 2021). Also, in a sample of 365 listed Italian firms, Amore *et al.* (2022) found that FFs outperformed non-family ones after COVID-19. Contrary to this, Kryeziu *et al.* (2022) found in a set of 320 SMEs that FFs were more affected by COVID-19 and experienced higher income declines.

A second line of research aims to delve deeper into these inconclusive results in order to understand how resilience differs within the FF label. As Calabrò *et al.* (2021, p. 2) state, "the focal question of interest is how FFs differ in their crisis management and why some FFs are more resilient than others." In this sense, FF researchers provide evidence that during a crisis, there are changes in FFs' strategic behaviors (Le Breton-Miller and Miller, 2022; Leppäaho and Ritala, 2022; Rivo-López *et al.*, 2020) and/or in relevant FF features that may explain their resilience results (Czakon *et al.*, 2022; Zahra, 2022).

In this line, we argue that on the one hand, according to strategic resilience research (Iborra *et al.*, 2020, 2022), firms' exploitation and exploration behaviors play a role in recovery from global crises; on the other hand, FFs are heterogeneous, which can affect their lack of recovery.

2.2 Family firms' exploitation and exploration behaviors and non-recovery

How firms behave during a crisis and how this relates to minimizing its consequences has been a core part of strategy research. Specifically, researchers have tried to understand how turnaround strategies that rely on some types of exploitative, explorative behaviors or both can help overcome this situation (Dolz *et al.*, 2019; Iborra *et al.*, 2020; Schmitt and Raisch, 2013).

Exploitation and exploration orientations have been analyzed at various levels; specific ones, e.g. exploitative and explorative innovation (Arzubiaga *et al.*, 2019), as well as general ones, like this study, in which exploration and exploitation orientations are defined at the firm

level (Iborra *et al.*, 2020). Exploitative firms concentrate on freeing up resources, establishing key priorities and improving efficiencies (e.g. layoffs or wage cuts), while explorative companies aim to develop new markets, products, or technologies, thereby obtaining new revenue sources (Schmitt and Raisch, 2013).

March (1991) described exploitation in terms of refinement, efficiency and productivity. In the case of FFs, researchers indicate that they can adopt an exploitation orientation because they monitor operations closely, thereby ensuring cost savings and efficiency (Gedajlovic *et al.*, 2012).

Researchers have analyzed the impact of exploitation on the lack of recovery. Furthermore, several studies have shown that exploitative behavior in crisis situations involves cost-saving activities, reductions in raw material costs, wages and incentives and lowering business costs related to marketing, logistics, or other functions (Iborra *et al.*, 2022; McGuinness *et al.*, 2018). In the context of a global crisis, many firms embrace exploitative behavior. This is because retrenchment activities may help them survive, reducing the likelihood of bankruptcy, although they may not fully recover. In order to achieve recovery, new revenue sources must be found (Schmitt and Raisch, 2013).

In addition, we argue that FFs' exploitative responses in reaction to events, such as COVID-19, can also adversely affect their Socioemotional Wealth (SEW). In contrast to exploitative behavior, ensuring job stability or caring for close relational connections with suppliers when facing hardship (Calabrò *et al.*, 2021; Le-Breton-Miller and Miller, 2022; Zahra, 2022) will help preserve the bonds with employees and stakeholders. For example, Rivo-López *et al.* (2020) observed that FFs that had developed emotional bonds with their employees responded during the GFC by maintaining these ties and firing fewer people than non-FFs. Also, Le-Breton-Miller and Miller (2022) describe that some FFs reacted to COVID-19 with strong and superior relationships with employees.

In summary, a too strong focus on exploitative behavior can hinder activities that might contribute to recovery, as well as damage the bonds with employees or stable stakeholders, thereby weakening their psychological attachment to the organization and reducing their long-term commitment. As a result, exploitative-oriented FFs are more likely to fail to recover. Therefore, we can state that in the context of an external crisis,

H1. There is a positive relationship between exploitation orientation and non-recovery in FFs.

March (1991) described exploration in terms of variation, experimentation and innovation. Full recovery may require efforts based on quick awareness of disruption and changes by developing novel alternatives and providing unconventional responses. These types of strategic behaviors are linked to experimentation. Additionally, some authors in the resilience literature highlight that recovery from a disruptive event relies on novelty and responding to adversity through increased innovation (Williams *et al.*, 2017).

Exploration behavior allows for supporting new proposals and gaining relevant knowledge that can be applied to new products and markets (Schmitt *et al.*, 2010) expanding their revenue streams.

According to Moreno-Menéndez *et al.* (2021), FFs' tendency to protect their social status and identity may explain why they react to unexpected environmental changes by improving their resilience. Campopiano *et al.* (2019) state that resilient FFs can benefit from unexpected environmental changes, since these will encourage them to capitalize on business opportunities created by these changes. Thus, explorative behavior may increase FFs' capacity to absorb and react to environmental jolts (Campopiano *et al.*, 2019).

Explorative behavior is associated with higher risks and uncertain results. FFs tend to adopt risk-averse behaviors. However, recent research highlights that these firms will transition to risk-taking behaviors when faced with disruptive events that challenge their

survival. For example, Mahto *et al.* (2022) confirmed this tendency by examining 20 cases following an earthquake in Chile. In an exploratory single-case study, Leppäaho and Ritala (2022) found support for risk-taking behavior and innovation during exogenous shocks. Their study of Finnboat, a traditional Finnish FF, shows how this family enterprise engaged in exploration and risk-taking behavior to achieve increased performance during the 1990, 2008 and COVID-19 crises. Also, in analyzing FFs, Arzubiaga *et al.* (2019) state that launching new products or offering new services to a market can lead to increased revenue. So, we can expect that FFs engaging in explorative behavior will increase their revenue sources when confronted with events that threaten their future. Accordingly, we can state that in the context of an external crisis,

H2. There is a negative relationship between exploration orientation and non-recovery in FFs.

2.3 Family-owned firm heterogeneity and non-recovery

FFs differ in specific characteristics that may impact their control over key behaviors when hit by a global crisis. In that sense, we argue that the heterogeneity of FFs may help explain the likelihood of non-recovery. Calabrò *et al.* (2021) suggested it would be interesting to analyze which features of FFs matter most for understanding their resilience. FFs may differ in terms of their size, the degree to which the family is involved in management, the generation in charge and/or the stage of their life cycle. These variables influence other corporate aspects, such as their governance mechanisms, the nature of their goals and strategic behaviors (Arteaga and Escriba-Esteve, 2021; Calabrò *et al.*, 2022a). We argue that these aspects, in turn, affect their likelihood of non-recovery.

Family involvement in management (FIM), implies that FFs differ in the degree to which they are managed by family or non-family members (Arteaga and Escriba-Esteve, 2021). FIM captures the extent to which family members influence strategic decision-making, firm actions and behaviors (Zahra, 2003).

FIM may take on various forms, such as membership in the top management team, board positions, with one of the critical distinctions being the presence or absence of a family chief executive officer (CEO) (Stanley *et al.*, 2019; Nordqvist *et al.*, 2014).

Stanley *et al.* (2019) argue that the existence of a family CEO increases the likelihood that the firm will rely on a single decision-maker and that this family CEO will dominate the key decisions. Additionally, Gedajlovic *et al.* (2012) state that FFs have extensive control over company activities and the discretion to take necessary measures in crisis situations.

Under disruptive conditions, family CEOs can be clearly relevant since their position explicitly grants them the power to influence the company's actions. When a family member is the CEO of a firm, he/she will be able to respond to events more quickly than non-family CEOs and take appropriate action. From day one, a family CEO strives to be in control of the situation, and he/she has more power and discretion than non-family CEOs to seize environmental challenges and reconfigure their firms accordingly. Czakon *et al.* (2022) support the idea that FF owners involved in management may have developed a resilience mindset, i.e., they believe that their firm can survive any crisis.

In contrast, when under those unusual circumstances, the CEO is not a family member, it may take longer for him/her to respond and will take safer, more conservative measures, which could delay recovery and put the firm's financial health at risk. Kraus *et al.* (2020) examined 27 cases of company managers confronted with the COVID-19 crisis. They found that in crisis situations, family owners' interests may diverge from those of non-family managers, who may take decisions that reduce the speed of action.

Therefore, we may anticipate that FFs with FIM -with a family CEO–will have the power and discretion to respond swiftly to changes in the environment. Accordingly, we can state that in the context of an external crisis,

H3. There is a negative relationship between FIM and non-recovery.

The generation in control (or the generational stage) (GC) is one of the key elements that help to distinguish the stage of the lifecycle of the FF (Magrelli *et al.*, 2022; Stanley *et al.*, 2019). The GC is a factor that introduces different levels of complexity in terms of personal and family relationships (Arteaga and Escriba-Esteve, 2021) and can affect the likelihood of recovery from a crisis such as COVID-19. In this line, Meroño-Cerdán (2023, p. 1) states that in "*situations of vulnerability (i.e., performance below aspirations), SEW and economic objectives are aligned, activating SEW as a catalyst for change,*" and that this alignment varies with the GC. In this regard, Beck *et al.* (2011) demonstrated that when first generations are in control, they show higher levels of market-oriented behaviors than later generations and this market orientation can influence the chances of recovery.

Arrondo-García *et al.* (2016) evidenced that first-generation FFs grew more during the GFC than their later-generation counterparts. As they demonstrate in a sample of large private Spanish FFs, the importance of preserving SEW in crises is higher for the first generation than for the later generations, where family ties weaken and differences between family branches emerge, since, in later-generational stages, several categories of owners, including relatives by marriage, coexist (Nordqvist *et al.*, 2014). Also, Rivo-Lopez *et al.* (2020) argue that later generations place less weight on socio-emotional goals than financial goals.

Consequently, in the event of an external crisis, we can expect that,

H4. A firm's lack of recovery is lower when the first generation is in control.

One of the key elements in determining the stage of an FF's life cycle is its size (Stanley *et al.*, 2019), which is a factor in differentiating FFs [1] (Arteaga and Escriba-Esteve, 2021).

Company size is closely related to FFs' survival, investment activities and needs (Nordqvist *et al.*, 2014). The size of FFs has been associated with a more dispersed distribution of ownership and additional complexity in their structure and hierarchical system, which lead to less engagement with the FF's emotional goals. However, in terms of financial goals, size has been linked to financial resources availability during a crisis (McGuinness *et al.*, 2018). In this sense, Crespí and Martín-Oliver (2015) argue that lenders may be less reluctant to lend to FFs during a crisis. Using a sample of 19,443 firm-year observations, they found that during the GFC, FFs had greater access to finance compared to non-FFs and that funding depended on the FF's' size. We argue that larger FFs will have better access to finance and other resources during turbulent times. Therefore, we can expect that, in the context of an external crisis,

H5. There is a negative relationship between firm size and non-recovery in FFs.

Finally, age is also related to the FF life cycle (Stanley *et al.*, 2019). FFs in the early stages of their life cycle tend to be less professionalized than their mature counterparts and prefer less formal governance mechanisms (Nordqvist *et al.*, 2014).

Age has been linked to key choices made by FFs during crises. In crisis situations, firms' survival may be at risk, so it can be expected that more established FFs will fight to preserve their welfare. In this sense, based on the SEW theory, Miralles-Marcelo *et al.* (2014) contend that FFs' age may affect performance because older FFs will be more concerned with the continuity and preservation of their business in order to ensure their family's welfare and reputation. Hence, we can argue that, in the context of an external crisis,

H6. There is a negative relationship between age and non-recovery in FFs.

Several of the above-mentioned potential antecedents of the likelihood of non-recovery have been the focus of separate research. However, some researchers provide reasons for thinking that these factors may act together and encourage us to seek to understand how different combinations of these antecedents lead to non-recovery (Calabrò *et al.*, 2021). For example, De Massis *et al.* (2019) state that FF behaviors regarding innovation and strategic change (i.e. exploration orientation) differ due to FF heterogeneity. According to the SEW theory, the FF's unique traits and loss aversion characteristics will influence their investment decisions in risky exploration activities (Chrisman and Patel, 2012). Also, Stanley *et al.* (2019) argue that the FF literature has begun to acknowledge the underlying heterogeneity among FFs and has obtained evidence for its impact on innovative orientations. For example, Beck *et al.* (2011) claim that the market orientation of the GC fosters innovation and that subsequent generations exhibit less market-oriented behavior. Thus, the combinations of FF heterogeneity and strategic behavior may affect their likelihood of non-recovery.

Complexity theory supports the argument that when different antecedents are combined, the presence or absence of certain components in the combination might positively or negatively impact the outcome variable (Gligor and Bozkurt, 2020). This might provide researchers with different possibilities by which a confluence of causes leads to a specific outcome, in our case, a failure to recover. For this reason, we investigated the presence of logical implications or set relationships in terms of necessity and sufficiency (Thomann and Maggetti, 2020). In summary, we expect the following:

Research Proposition: Different combinations of strategic choices, SEW priorities and FF traits may drive FFs to non-recovery and both types of strategic behavior (exploitation, exploration) may be contingent on family SEW priorities but also on FF heterogeneity, wherein factors such as family detachment, the first generation not being in charge of the firm or the small size and young age of the firm may be contributing causal conditions that prevent FFs from recovering during times of global crisis.

However, we do not expect any of these causal conditions to be absolutely necessary for non-recovery.

3. Methods

3.1 Data collection and sample description

Family business data was collected globally by the STEP Global Family Business Survey, COVID-19 edition. The survey was launched in June 2020. For this study, we focused on a sample of 842 FFs from eight European countries. Countries were included when at least 40 questionnaires were available. The firms selected were those from non-resilient industries (neither electricity, gas, steam and air conditioning supply nor human health and social work activities were included) in which family ownership exceeded 50%. Observations corresponding to micro FFs with less than or equal to 10 employees were removed from our sample. Appendix 1 contains information about the respondents.

3.2 Variables and measures

3.2.1 Non-recovery. Resilience was measured by sales recovery in October 2020 compared to the pre-pandemic period in the country of each company in our sample. The variable called *Non-recovery* takes three values: revenue does not return to its previous level = 1; revenue reached its previous level = 0; revenue has increased = – 1. Revenue is a variable directly affected by demand changes due to external shocks. Smallbone *et al.* (1999) found that downturns affect revenue first, then profitability and finally, survivability.

3.2.2 Exploitation and Exploration orientations. We used 12 items to measure *Exploitation* (Appendix 2). Responses to these items in the survey are dichotomous (yes or no), so we chose

an approach based on the extent of change to operationalize the construct. Consequently, the *Exploitation* variable was constructed as the sum of the items' values (1 or 0) divided by the number of items. This approach to operationalizing strategy change has been previously used in the literature (Goodstein and Boeker, 1991; Zajac and Shortell, 1989).

We measured the *Exploration* construct with 5 items (Appendix 2). Unlike the questions related to the items used to assess exploitation, which were binary, those pertaining to exploration were answered using a five-point Likert scale. The *Exploration* construct was subjected to a confirmatory factor analysis (CFA) with structural equation modeling (SEM) techniques. This provided a model suitable for the proposed one-factor structure, with values that are considered acceptable ($\chi^2 = 35.3$, $df = 5$, $p = 0.00$, adjusted goodness-of-fit index (AGFI) = 0.95, comparative fit index (CFI) = 0.97 and root mean square error approximation (RMSEA) = 0.08). All items were loaded on the construct with a standardized factor loading of ≥0.6 and were statistically significant ($p < 0.01$). This result provides evidence of convergent validity. We measured the construct through factorial punctuations (subsequently normalized on a 0 to 1 scale) to be able to work with observable variables due to the constraints of the statistical techniques used.

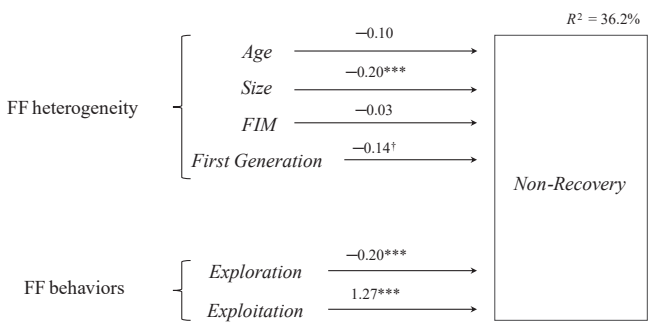
3.2.3 Age, size, first generation and FIM. *Age* is the company's years as of October 2020. *Size* is the number of full-time employees at that date. *First generation* is a dichotomous variable that measures whether the first generation is involved in the management of the company (value 1) or not (value 0). And *FIM* measures if the firm's CEO is from the family, taking the value of 1 if yes and zero otherwise (Arteaga and Escribá-Esteve, 2021).

3.3 Regression analysis

First, we used ordinal regression analysis to explore the relationship between *Non-recovery* and the variables of interest. Appendix 3 provides the descriptive statistics, and Figure 1 and Table 1 show the regression results.

Table 1 shows that *Exploitation* has a significant positive direct effect on *Non-recovery* and that *Size*, *First Generation* and *Exploration* have a significant negative direct effect on *Non-recovery*. Thus, hypotheses 1, 2, 4 and 5 are supported. Contrary to expectations, *Age* and *FIM* do not have a significantly negative relationship with our dependent variable. Hence, hypotheses 3 and 6 are not supported.

Additionally, we tested the model with direct effects and interactions between FF behaviors (*Exploitation* and *Exploration*) and FF heterogeneity (*Age*, *Size*, *First generation*



Note(s): †$p < 0.10$; ***$p < 0.001$
Source(s): Figure by authors

Figure 1.
Hypothesis testing via ordinal regression

and *FIM*) and the new eight terms add very little to the explanatory power ($\Delta R^2 = 1.43\%$) of the model without interactions and the $\Delta\chi 2$ is not statistically significant.

3.4 QCA analysis

We used fsQCA (Ragin *et al.*, 2007) to create the data set and construct the truth table from fuzzy-set data.

The prefix fs precedes the names of the variables to denote the calibrated condition used in the fsQCA analysis. In some cases, the variable's name in the regression analysis was deliberately changed to clarify its meaning, e.g. *Age* was changed to *Old* (degree of membership in the set of old firms). Moreover, the symbol ~ means "no" or the absence of the condition. Consequently, the variable *Non-recovery* is named ~ *fsRecovery* in the fsQCA analysis.

While the regression analysis results indicate a positive linear relationship between *fsExploitation* and ~*fsRecovery*, the results presented in Figure 2 show a significant number of cases where ~ *fsRecovery* is high and *fsExploitation* is low (positive contrarian cases) and many cases where ~ *fsRecovery* is low and *fsExploitation* is high (negative contrarian cases), which justifies the complementary use of qualitative comparative analysis (QCA).

We transformed the variables into fuzzy-set membership scores using three anchors (direct method). The selected thresholds for full membership, full non-membership and crossover points are reported in Appendix 4. We used the following model:

$$\sim fsRecovery = \mathrm{f}(fsExploitation, fsExploration, Big, Old, FIM, First\ Generation)$$

We did not identify any necessary conditions for non-recovery (see Appendix 5) with a consistency value greater than or equal to 0.9 (Ragin, 2006). The truth table is reported in Appendix 6. We set the frequency cutoff to 3 and the consistency cutoff to 0.84. Proportional Reduction in Inconsistency (PRI) consistency always exceeded 0.7 for positive configurations (Greckhamer *et al.*, 2018; Pappas and Woodside, 2021).

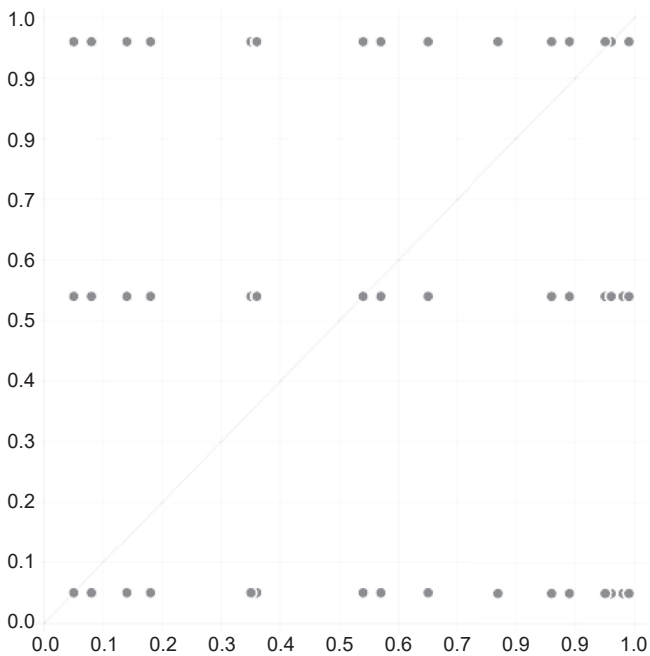
3.5 QCA results

Table 2 shows the combinations that lead to non-recovery (~*fsRecovery*) following the guidelines suggested by Ragin and Fiss (2008) to display the results and illustrate the presence (●; black circles) or absence (⊗; crossed-out circles) of certain conditions. While large circles indicate core conditions, small circles refer to peripheral conditions. Blank spaces in a solution indicate a "don't care" situation in which the causal condition may be present or absent. Specifically, ten solutions were identified, supporting the anticipated research hypotheses. Namely, various configurations of strategic behavior and family traits that exhibit acceptable consistency (≥ 0.80; Ragin, 2008) are equifinal, leading to non-recovery.

Table 1.
Analysis of *non-recovery* via ordinal regression

Variable	B	*p*-value	95% CI	
Age	−0.10	0.18	−0.24	0.05
Size	−0.20	0.00	−0.32	−0.09
FIM	−0.03	0.57	−0.14	0.08
First Generation	−0.14	0.05	−0.28	0.00
Exploration	−0.20	0.00	−0.32	−0.09
Exploitation	1.27	0.00	1.10	1.45
−2 Log Likelihood	1260.94	0.00		
Nagelkerke R^2	36.2%			

Source(s): Table by authors



Note(s): ~fsRecovery (Y) vs fsExploitation (x)
Source(s): Figure by authors

Figure 2.
Fuzzy XY plot

Condition	Conf. 1	Conf. 2	Conf. 3	Conf. 4	Conf. 5	Conf. 6	Conf. 7	Conf. 8	Conf. 9	Conf. 10
fsExploitation	●	●		●	●		⊗			●
fsExploration			•	⊗	⊗		⊗	⊗	⊗	•
Big		⊗	⊗		⊗	⊗	⊗	●	⊗	
Old	•	●	⊗	•		•	⊗	•	•	⊗
FIM				⊗		⊗	⊗	⊗	●	⊗
First generation	⊗		⊗		•	•		⊗	⊗	•
raw coverage	0.44	0.44	0.21	0.23	0.08	0.07	0.16	0.12	0.11	0.07
unique coverage	0.06	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.02	0.01
consistency	0.89	0.91	0.86	0.92	0.88	0.84	0.87	0.87	0.89	0.89
solution coverage					0.64					
solution consistency					0.85					

Note(s): ● = core causal condition (present); ⊗ = core causal condition (absent)
• = contributing causal condition (present); ⊗ = contributing causal condition (absent)
Source(s): Table by authors

Table 2.
Configurations leading to non-recovery

The results in Table 2 show an overall solution coverage of 0.64 and an overall solution consistency of 0.85, indicating that these ten alternative configurations capture a significant part of non-recovery. Configurations 1 and 2 have the highest raw coverage (0.44) and represent the most parsimonious (three-condition recipe) combination of attributes that provides the most accurate picture of non-recovery. Configuration 1 indicates that firms are not resilient when the following conditions are simultaneously present: (1) high levels of exploitative activity, (2) the FF is old and (3) the family business is not in the first generation.

These ten combinations linked to non-recovery are similar in that they all include exploitation and/or exploration behaviors and some aspects of firm heterogeneity (size, family involvement, generation in charge and/or firm age). Five configurations (1, 2, 4, 5 and 10) include embracing an exploitative behavior (*fsExploitation*) as a decisive causal ingredient and another five (4, 5, 7, 8 and 9) exclude an explorative behavior (~*fsExploration*) as a core causal condition. Three configurations (7, 8 and 10) comprise family detachment (~*FIM*) as a decisive causal ingredient and another three (1, 3 and 9) contain the first generation not being in charge (~*First Generation*) as a core causal condition. Surprisingly, configuration 9 shows that even when the family is involved in management, FFs are not resilient when (1) there are low levels of explorative activity, (2) the company is not big, (3) the firm is old and (4) the family business is not in the first generation. These results confirm that the causal conditions linked to non-recovery are combinatorial in nature and that it is possible to discern relevant combinations when cases are viewed as configurations.

Appendix 7 provides and in-depth discussion between both methodologies.

4. Conclusions

COVID-19 has brought substantial changes for all of us and created new challenges for FFs that demand our attention (Zahra, 2022). Some of the unresolved questions include whether FFs outperform non-FFs, why they do so if they do, or what specific features of FFs or constellations may help explain their results (Calabrò *et al.*, 2022a; Le-Breton-Miller and Miller, 2022). Our results provide evidence that the lack of resilience in our sample is relevant, as 60% of FFs did not recover their sales, highlighting the need to understand this phenomenon.

Following recent works, in this study, we developed a model showing that their behavior and specific family attributes may explain their lack of recovery in times of crisis. We provide evidence that both FF behaviors and FF attributes are relevant, i.e., they matter in explaining the lack of recovery.

In terms of behavior, FFs respond to opportunities and threats brought on by disruptive and extraordinary crises (Kraus *et al.*, 2020; Leppäaho and Ritala, 2022; Mahto *et al.*, 2022). We show that FFs' explorative and exploitative behaviors have different effects on the chances of recovery. Our results are consistent with Kraus *et al.* (2020), who, based on 27 cases, found that FFs pursue different strategies in the short term to adapt to crises and become stronger in the long run. FFs adapt their business models to changing environmental conditions faster.

Contrary to what one would expect in normal times, our research shows that FFs that achieve recovery are those firms that engage in extraordinary levels of exploration, innovation and risk-taking (Leppäaho and Ritala, 2022; Mahto *et al.*, 2022). They seek creative ways to find effective solutions to unprecedented circumstances (Iborra *et al.*, 2020, 2022; Leppäaho and Ritala, 2022). Similar to what Leppäaho and Ritala (2022) concluded through a case study, when FFs see bankruptcy as a possibility, they can shift from their risk-averse orientation to a risk-taking one. The QCA results reinforce this view. Given that in each of the configurations provided, exploration appears as a core dimension for explaining FF recovery, we may state that exploration decreases the likelihood of non-recovery, while the absence of exploration is core to explaining non-recovery in five of the configurations.

As expected, we find that exploitation behaviors are linked to non-recovery. FFs are well known for their strong control and efficiency capabilities, but the COVID-19 crisis created an entirely different environment. As shown by Le Breton-Miller and Miller (2022), it was, in a way, a "moment of truth," in which FFs' bonds and engagement with their employees, stakeholders, suppliers and local communities came first, preserving their SEW (Calabrò *et al.*, 2021; Le-Breton-Miller and Miller, 2022; Zahra, 2022). Our regression analysis confirms these findings and provides evidence for the strong negative effect of exploitation on non-recovery, which also clearly appears in half of the configurations, especially the first two with higher coverage.

Regarding FF attributes, not all factors considered affect non-recovery. Although we expected FIM to affect recovery, we did not find a significant association. This result is in agreement with Amore *et al.* (2022), who found that FFs outperform non-family ones, no matter whether the CEO is a family member or not. An additional explanation may come from our sample. We focused on FFs in which the family owns at least 50% of the shares and found out that in the context studied, FIM is not relevant, since family members will play a relevant role when recovery is at risk, regardless of whether the CEO belongs to the family or not.

Firm age is also not related to lack of recovery. Age is typically linked to experience and FFs' belief that they can survive any crisis (Czakon *et al.*, 2022). However, our results do not confirm this point. In fact, they open the question of whether experience is always positive and also if global crises are so different that they should be treated as rare events (Zollo, 2009), in which firms – especially FFs whose owners have a natural obligation to consider previous experience (Czakon *et al.*, 2022) – are confronted with superstitious learning.

We did find that lack of recovery is associated with FF size and the generation responsible for the firm, specifically, that there is a lower likelihood of non-recovery when the family's first generation is in control and the FF is large. The results of our analysis concerning the generation in charge also raise questions about the role of experience. Recent studies highlight that FFs, with later generations in charge, have survived generational change, thereby enhancing their ability to adapt and respond to complex situations, providing them with a high level of resilience (Ventura *et al.*, 2020). Our results do not confirm that acquiring experience in dealing with internal events during generational change increases resilience to external events.

fsQCA sheds some light on this. According to our results, big FFs have a higher likelihood of failing to recover if they are old, not run by a family CEO and not managed by the first generation. It seems that in such cases, critical facets related to superior resilience, such as rapid adaptation of business models, strong cohesion and solidarity (Kraus *et al.*, 2020), would have been lost. On the other hand, old small FFs do not recover (configuration 2), even if they are managed by a family CEO from a later generation. In this latter case, family CEOs can use their discretion and power to engage in behaviors aimed at short-term benefits for family members instead of long-term resilience (Le Breton-Miller and Miller, 2022). Two other family configurations are linked to non-recovery: young firms with a non-family CEO and young firms with the second or later generations in charge.

4.1 Practical implications

Although an external crisis such as COVID-19 is unlikely to occur again to the same extent, other events may occur and impact FFs. Understanding how FFs can avoid non-recovery can inform managers about how to deal with stressful events, thereby reducing the likelihood of non-recovery during disruptions, and it can also provide guidance to economic authorities on how to help FFs around the world avoid non-recovery, which affects the economy. Although our study shows that FF exploration behaviors are key to recovery, this is a challenging requirement because, under normal circumstances, innovation is a challenge for many firms,

especially for FFs. It is evident from this study that no single recipe applies to all FFs, but different configurations of FFs may be linked to the likelihood of non-recovery. Managers cannot easily change the firm size or age, but they can bring about changes to FIM or use the experience and knowledge of the first generations.

4.2 Contributions

This study makes several contributions. First, it contributes to FF research by offering a theoretical explanation for the different effects of FF attributes on non-recovery in a global crisis. Second, it contributes to the growing literature on organizational resilience by investigating explorative and exploitative behaviors as antecedents of FF non-recovery. Third, we show that combining fsQCA and traditional regression analysis to comprehend complex phenomena is useful.

In that sense, as previous studies in different disciplines have shown (e.g. Gligor and Bozkurt, 2020; Pappas and Woodside, 2021), this study makes methodological contributions to FF research by going beyond the "all-or-nothing" association assumed by the widely used regression models. This manuscript demonstrates the convenience of using multiple methods to deal with the complexity inherent in the causal relationships of the variables of interest. Although each method has inherent limitations, combining both can offer a more comprehensive perspective of causal relationships than either approach used alone. For example, previous studies showed direct links between recovery and exploitation, exploration, age and size (Iborra *et al.*, 2020). Our findings suggest that the presence of all of these variables is not always necessary. In particular, a combination of one of these factors with the presence of some of the other factors can compensate for the absence of any of them.

4.3 Limitations

The study has certain empirical limitations. We measured two constructs with adapted scales, and we have not been able to control for aspects such as companies' pre-pandemic financial health due to limited data in the STEP questionnaire. However, the database contains a large number of companies from many industries and countries, which allows us to obtain reliable statistical contrasts. Moreover, the recipes found for this sample of FFs proved the existence of several equifinal configurations leading to non-recovery. In this regard, set-theoretic methods allow for a detailed analysis of the prerequisites for non-recovery configurations. Nevertheless, it is imperative to note that these methods also contemplate causal asymmetry, since configurations that result in non-recovery may be different from those that result in high recovery.

4.4 Future research agenda

The findings and conclusions of this study provide valuable insights into the behavior and attributes of FFs and their impact on recovery during crises. Based on these conclusions, several future research directions can be identified. First, this study focused primarily on the immediate impact of FF behaviors and attributes on recovery during the pandemic. Future research could explore the long-term effects of these factors on FF performance. Understanding how FFs evolve and adapt over time will provide a more comprehensive understanding of their recovery capabilities. Second, while this study focused on the COVID-19 pandemic, FFs might face other crises. Future research could explore how FF behaviors and attributes influence recovery in different crisis contexts. Third, we found that both FF behaviors and attributes play a role in recovery. Future research could delve deeper into their microfoundations to understand the underlying mechanisms. For example, examining FFs' decision-making processes, strategic choices and resource allocation

strategies during crises could provide valuable insights into their recovery dynamics. Finally, the study's limitations have important implications for future research.

Note

1. While the features discussed in hypotheses 3 and 4 are specific to FFs, size and age explain firm heterogeneity both in FFs and non-FFs. We acknowledge one reviewer for this point.

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Appendix 1

	N	%
Position		
CEO	381	45.2%
Board member	176	20.9%
TMT member	121	14.4%
Other*	164	19.5%
Total	842	100.0%
Do you belong to the owning family?		
Yes	721	85.6%
No	121	14.4%
Total	842	100.0%

Note(s): *Basically, people who hold several of the above positions (e.g. TMT managers who sit on the board), general managers of not-limited liability companies who are not formally CEOs, shareholders who are not on the board, shareholders of companies without a board of directors, top executives of firms without a board of directors and/or management team, and managers who are not part of the management team
Source(s): Table by authors

Table A1. Information about the respondents

Appendix 2
Exploration and exploitation items

Exploitation items

(1) Regarding employees: reducing employee hours; reducing employee pay; laying off employees; putting employees on furlough; moving all or some employees to remote positions, and freezing all hiring.

(2) Related to executives: considering alternative types of incentive compensation and deferring or reducing executive pay

(3) Business-related items: temporarily closing down my business, closing down my business permanently, renegotiating vendor contracts, and delaying payment of all or part of vendor bills and loan obligations.

Exploration items

(1) Explored new revenue-generating products and services to be offered during the COVID crisis.

(2) Encouraged revenue-generating ideas from the next generation of family business members.

(3) Quickly and cheaply developed new ideas that were in high demand during the crisis.

(4) Looked for opportunities to extend existing capabilities to new markets.

(5) Invested in new ideas, products, and services.

Appendix 3

Variable	Mean	S.D.	1	2	3	4	5	6
1. Non-recovery	0.45	0.75						
2. Age	59.24	46.88	−0.01					
3. Size	736.70	3890.32	−0.05	0.29				
4. FIM	0.33	0.47	−0.01	0.01	0.02			
5. First generation	0.25	0.43	−0.04	−0.64	−0.19	0.02		
6. Exploration	0.57	0.28	−0.10	−0.06	0.01	−0.06	0.03	
7. Exploitation	0.34	0.23	0.47	0.02	0.16	−0.01	−0.03	0.02

Note(s): All correlations equal to or above |0.10| are statistically significant at $p < 0.01$ (bilateral)
Source(s): Table by authors

Table A2.
Descriptive statistics

Appendix 4

Fuzzy set label and definition	Fuzzy set type	Fully out	Crossover point	Fully in
Sales-Resilient Firms (*fsRecovery*). Degree of membership in the *fsRecovery* set	Three-value fuzzy set (−1; 0; 1)	−1	−0.05	0.9
Firms taking Exploitation actions (*fsExploitation*)	Fuzzyor (EMA, EXA, BUA)			
Firms taking Employee actions (EMA). Degree of membership in the EMA set	Seven-value fuzzy set (0; 16.7; 33.3; 50; 66.7; 83.3; 100)	0	41.5	83
Firms taking Executive actions (EXA). Degree of membership in the EXA set	Three-value fuzzy set (0; 50; 100)	0	47.5	95
Firms taking Business actions (BUA). Degree of membership in the set of BUA	Nine-value fuzzy set (0; 12.5; 25; 37.5; 50; 62.5; 75; 87.5; 100)	5	46	87
Strategically exploring firms (*fsExploration*). Degree of membership in the set of *fsExploration*	Continuous fuzzy set [−2.5; 2.1]	−1.85	−0.125	1.6
Large Firms (*Big*) Degree of membership in the *Big* set	Continuous fuzzy set [11; 90,000]	15	249	2460
Old Firms (*Old*) Degree of membership in the *Old* set	Continuous fuzzy set [5; 786]	6	24.5	140
Family CEO (*FIM*) or not	Crisp (binary) set			
First Generation (*First Generation*) or not	Crisp set			

Source(s): Table by authors

Table A3.
Calibration parameters

Appendix 5

Condition	Consistency	Coverage
fsExploitation	0.65	0.89
~*fsExploitation*	0.49	0.69
fsExploration	0.63	0.76
~*fsExploration*	0.51	0.83
Big	0.34	0.78
~Big	0.77	0.76
Old	0.71	0.77
~Old	0.43	0.83
FIM	0.33	0.69
~FIM	0.67	0.70
First generation	0.24	0.67
~First generation	0.76	0.70

Note(s): Outcome variable: ~*fsRecovery*
Source(s): Table by authors

Table A4.
Necessary conditions

Appendix 6

fsExploitation	*fsExploration*	*Big*	*Old*	*FIM*	*First generation*	Number	*~fsRecovery*	Raw consist.	PRI consist.	SYM consist.
1	0	0	1	1	0	28	1	0.942	0.913	0.916
1	0	1	1	1	0	18	1	0.932	0.885	0.893
1	1	0	1	0	1	13	1	0.93	0.895	0.895
1	0	0	0	0	1	16	1	0.929	0.892	0.892
1	0	0	1	0	0	44	1	0.922	0.887	0.887
1	0	1	1	0	1	6	1	0.919	0.836	0.836
1	1	0	1	1	0	36	1	0.919	0.883	0.892
1	0	0	1	0	1	7	1	0.919	0.862	0.862
1	1	0	0	1	0	3	1	0.917	0.875	0.875
1	0	1	1	0	0	32	1	0.907	0.844	0.847
1	1	0	0	0	1	23	1	0.905	0.866	0.877
1	1	0	0	0	0	4	1	0.904	0.848	0.849
1	1	1	1	1	0	24	1	0.903	0.844	0.848
1	1	0	1	0	0	95	1	0.895	0.856	0.859
0	0	0	0	0	0	4	1	0.887	0.797	0.797
1	1	0	0	0	1	4	1	0.883	0.786	0.786
0	0	0	1	1	0	31	1	0.867	0.771	0.808
0	0	1	1	0	0	22	1	0.865	0.727	0.731
1	1	0	1	1	1	10	1	0.859	0.785	0.785
0	0	0	1	0	1	9	1	0.859	0.741	0.741
0	1	0	1	0	1	15	1	0.853	0.759	0.762
0	0	0	0	0	1	8	1	0.849	0.746	0.765
1	1	1	1	0	0	61	1	0.849	0.771	0.772
0	1	0	0	0	0	7	1	0.847	0.732	0.733
1	0	0	1	1	1	6	1	0.845	0.722	0.722
0	1	0	0	1	0	4	1	0.844	0.751	0.751
1	0	0	0	1	1	5	1	0.841	0.734	0.742
0	0	1	1	1	0	15	0	0.839	0.694	0.726
1	1	1	1	0	1	9	0	0.839	0.704	0.704
0	0	0	1	0	0	50	0	0.837	0.741	0.755
1	1	1	1	1	1	7	0	0.836	0.726	0.726
0	0	0	1	1	1	8	0	0.825	0.618	0.625

(continued)

Table A5.
Truth table

Table A5.

fsExploitation	*fsExploration*	*Big*	*Old*	*FIM*	*First generation*	Number	*~fsRecovery*	Raw consist.	PRI consist.	SYM consist.
0	1	0	1	1	1	6	0	0.823	0.674	0.678
0	1	1	1	1	0	17	0	0.82	0.664	0.679
0	1	0	1	1	0	27	0	0.819	0.704	0.727
1	1	0	0	1	1	14	0	0.819	0.74	0.74
0	0	0	0	1	1	4	0	0.803	0.608	0.634
0	1	0	0	1	1	6	0	0.798	0.662	0.662
0	1	0	0	0	1	20	0	0.793	0.684	0.706
0	1	1	1	0	0	29	0	0.785	0.6	0.616
0	1	0	1	0	0	63	0	0.774	0.646	0.665

Source(s): Table by authors

Appendix 7
Results discussion: regression analysis versus fsQCA

Family businesses are widely known for their mastery of resilience and agility and for their adaptability to overcome any challenge, even if an economic crisis, such as that caused by COVID-19, stands in their way. However, 60% of the European questionnaires showed that revenue had not yet been recovered. Our analysis of European FFs that failed to recover their revenues due to the uncertainties of COVID-19 provides valuable insights into this phenomenon.

Data were analyzed using two distinct methodologies: ordinal regression and fsQCA. Ordinal regression results showed a significant positive relationship between non-recovery and exploitation, a negative relationship between non-recovery and size, generation and exploration and age and family involvement were not statistically significant (Table 1). Conversely, fsQCA unveiled ten different combinations of these antecedents that led to high levels of non-recovery (Table 2). Consistent with the idea of causal complexity, no single organizational characteristic or behavior is sufficient to explain the lack of recovery in the COVID-19 pandemic. Instead, this outcome is related to a number of sufficient combinations of conditions. Hence, our findings are at odds with the idea of considering single indicators, as complementarities affect the lack of recovery or other key performance metrics. This finding is in line with recent research using fsQCA that found a key role of FF configurations in explaining performance (Calabrò *et al.*, 2022b). Comparing the results obtained via ordinal regression with those obtained through fsQCA reveals some interesting insights.

First, the ordinal regression results suggest a significant positive relationship between non-recovery and exploitation. The fsQCA results, however, showed how several factors combine to create several distinct causal recipes that lead to the same outcome: non-recovery. In particular, significant levels of non-recovery occurred in the cases represented by configurations 1, 2, 4, 5 and 10 when high levels of exploitation were present as core conditions. Interestingly, a low level of exploitation as a peripheral condition resulted in high levels of non-recovery for the cases represented by configuration 7, which contradicts the findings proposed by the ordinal regression results. Furthermore, the presence or absence of exploitation makes no difference for the cases represented by configurations 3, 6, 8 and 9, which does not support the ordinal regression results.

Second, the ordinal regression results point to a significant negative relationship between non-recovery and exploration. However, the fsQCA results revealed a different version: low levels of exploration as a core condition resulted in high levels of non-recovery for the cases represented by configurations 4, 5, 7, 8 and 9. Interestingly, for the cases represented by configurations 3 and 10, high levels of exploration as a peripheral condition resulted in high levels of non-recovery, contradicting the findings proposed by ordinal regression results. Also, the presence or absence of exploration made no difference for the cases represented by configurations 1, 2 and 6, not supporting the ordinal regression results either.

Third, the ordinal regression results indicate a significant negative relationship between non-recovery and size, but the fsQCA results showed that for the cases represented by configurations 2, 3, 5, 6, 7 and 9, the risk of non-recovery was higher for small firms as a core and peripheral condition. Remarkably, greater size as a core condition led to high levels of non-recovery for the cases represented by configuration 8, which clearly contradicts the findings proposed by the ordinal regression results. In addition, size made no difference for the cases represented by configurations 1, 4 and 10, which contradicts the ordinal regression results.

Fourth, the ordinal regression results suggest a significant negative relationship between non-recovery and firm age. However, the fsQCA results showed that young age as a core condition resulted in high levels of non-recovery in the cases represented by configurations 3, 7 and 10. Actually, old age, mainly as a peripheral condition, resulted in high levels of non-recovery for the cases represented by configurations 1, 2, 4, 6, 8 and 9, which clearly contradicts the ordinal regression results. Also, age made no difference for the cases represented by configuration 5, which is not in line with the ordinal regression results.

Fifth, the ordinal regression results suggest a non-significant relationship between non-recovery and FIM, but the fsQCA results indicate that low levels of family involvement as core and peripheral conditions resulted in high levels of non-recovery for the cases represented by configurations 4, 6, 7, 8 and 10. Conversely, for the instances defined by configuration 9, a high level of family involvement as a core condition led to high levels of non-recovery, which clearly runs contrary to the ordinal regression

results. Moreover, family involvement makes no difference for the cases represented by configurations 1, 2, 3 and 5, which does not support the ordinal regression results.

Sixth, the ordinal regression results indicate a non-significant relationship between non-recovery and the involvement of the first generation in management. However, the fsQCA results showed that low levels of first-generation involvement as a core condition bring about high levels of non-recovery for the cases represented by configurations 1, 3, 8 and 9. Contrarily, high levels of first-generation involvement as a peripheral condition led to high levels of non-recovery for the cases represented by configurations 5, 6 and 10, which is not in line with the findings proposed by the ordinal regression results. Furthermore, first-generation involvement made no difference for the cases represented by configurations 2, 4, and 7, which does not support the ordinal regression results.

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The impact of multiple sources of employees' capital on judgments regarding potential for career advancement

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Abstract

Purpose – The human resource and talent management fields have been increasingly focusing on the process and criteria to identify employees' potential for career advancement due to their impact on the competitive advantage of organizations. This paper expands the extant theoretical and empirical evidence regarding these complex decisions, namely through the combined analysis of multidimensional sources of employees' capital.

Design/methodology/approach – This is a cross-sectional study. Data were collected from 384 individuals assessed by their line managers. The research model and hypotheses were tested using structured equation modeling.

Findings – The results show a positive and significant influence of four employees' capital sources, namely: human capital (what you know), social capital (whom you know), psychological capital (who you are) and reputational capital (how others perceive us) with regard to judgments of potential for career advancement. The model explains 52% of the total variance in those judgments.

Research limitations/implications – The data were collected using a questionnaire at a single point in time and thus, not allowing cause-effect inferences.

Practical implications – The results provide guidance to organizational leaders to improve the decision-making process regarding judgments of potential for career advancement.

Originality/value – To our knowledge, this is the first study to examine managers' judgments regarding the potential for career advancement using four sources of employees' capital: human, social, psychological and reputational capital. Furthermore, it considers that reputation plays a mediation role.

Keywords Career advancement, High-potentials assessment, Human capital, Social capital, Psychological capital, Reputational capital

Paper type Research paper

1. Introduction

Academic and business literature show that talent management (TM) has become a key part of human resource management (HRM) and human resource development (HRD) strategies in contemporary organizations (Cappelli and Keller, 2017; Jooss *et al.*, 2021a; McDonnell *et al.*, 2017). A key argument for positioning talent and its management as a source of competitive advantage can be found in the resource-based view (RBV) of the firm theory (Collings *et al.*, 2017a; Collins, 2021; Harsch and Festing, 2019).

The TM practices are crucial for ensuring employees' career outcomes as well as HRM/HRD effectiveness, among which stand out the evaluation of employees' promotability or potential for career advancement (PCA) and the criteria used for identifying high-potential

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(HP) employees (Collings *et al.*, 2017a; Finkelstein *et al.*, 2018). Furthermore, it has been acknowledged that organizations with reliable processes for predicting employees' PCA tend to acquire a competitive advantage (Hollenbeck and Jamieson, 2015; Jooss *et al.*, 2021b). The assessment of employees' potential entails a highly complex process that encompasses making decisions based on present estimates about something that can only be verified in the future and observing something that only exists in a small percentage of employees (Finkelstein *et al.*, 2018; Jooss *et al.*, 2021b; Silzer and Church, 2009). The predominant perspective on TM associates the concept of HP with employees' readiness to achieve career advancement, thus expressing employees' capability to assume, in the future, positions of greater complexity and responsibility (Cascio *et al.*, 2017; McDonnell *et al.*, 2017; Silzer and Church, 2010).

Furthermore, extant literature on HRM and HRD has considered different employees' capital sources – namely, human, social and emotional or psychological – as relevant determinants of employees' career advancement and success (Gratton and Ghoshal, 2003; Järlström *et al.*, 2020; Luthans *et al.*, 2007; Rabenu, 2021). Other characteristics have been suggested in the academic literature – for example, Sparrow *et al.*'s (2015) definition of talent includes reputational capital as well (RC).

This research responds to the recent call from HRM/TM scholars for more applied studies identifying criteria for making accurate predictions about how successful an employee might be in the long term. This fundamental research problem is related to two specific research questions:

RQ1. What is the incremental impact of each source of employees' capital, i.e. human capital, social capital, psychological capital and reputational capital, regarding the decisions on PCA?

RQ2. What is the type of relationship between the three traditional sources of employees' capital – human, social and psychological – and the emergent reputational capital?

This study has four main contributions to the HRM/HRD field. First, it presents a multidimensional framework using the concept of capital as a lens for understanding PCA judgments. Second, it analyzes the incremental or relative value of different sources of employees' capital for determining PCA. Third, it offers new evidence about the mediation role of RC with regard to human, social and psychological capital's influences on PCA. Finally, to our best knowledge, no extant study has analyzed these sources as part of a common framework for TM decisions.

The paper is organized as follows: we begin by presenting an extensive review of the literature on HRM/HRD, TM and promotability judgments, from which we then build our hypotheses and research model. Next, we present and explain the methodology used in the study. Then, the study's main findings are presented and interpreted. The paper ends with a discussion of the theoretical and managerial implications and possible directions for future research.

2. Literature review and hypotheses

In contemporary organizations, managing people effectively is widely recognized as a critical competitiveness factor (Lawler, 2017; Silzer and Church, 2010; Skuza *et al.*, 2021). Thus, the strategic role played by talent in ensuring organizational success and the HR practices necessary for attracting, developing and retaining workforce talent have emerged as core themes in HRM/HRD and TM (Gallardo-Gallardo *et al.*, 2020; Jooss *et al.*, 2021a; Khoreva *et al.*, 2017). Despite this emphasis, there is scant evidence that most organizations have successfully managed talent (Collings, 2014; Collings *et al.*, 2017b; Meyers *et al.*, 2013)

and understood who should be considered a talent and why (Harsch and Festing, 2019; Skuza *et al.*, 2021).

To address the aforementioned challenges, it is necessary to clarify the concept of talent. There are two main approaches or philosophies in this regard: one focuses on managing the talent of all employees (inclusive approach) and the other focuses on managing the talent of a sub-group of high-potential or high-performing employees (an exclusive approach) (Kwon and Jang, 2021; Thunnissen, 2016). Due to the growing interest in workforce differentiation, we will adopt the exclusive perspective in this study, which has increasingly dominated academic and business literature on TM (Collings *et al.*, 2017b; Kwon and Jang, 2021). This approach can facilitate a more deliberate utilization of organizational resources so that employers can invest substantially greater resources in the ones they believe will offer higher returns; it necessarily involves the proactive identification of employees with the potential to fill key positions within the organization structure (Crowley-Henry *et al.*, 2019; Day and O'Connor, 2017).

One recurring TM issue is determining the organization's talent pool. This group of employees includes both high performers who are now serving in strategic job roles and HP employees who may do so in the future (Jooss *et al.*, 2021b; Lawler, 2017; McDonnell and Skuza, 2022). One major challenge in identifying HP employees is the inherent complexity of making predictions about how successful a person might be in the long term. It involves defining what one is trying to predict, assessing a person against the appropriate criteria and making predictions about future performances (Silzer and Borman, 2017; Silzer and Church, 2009, 2010).

Due to the strategic and critical impact of workforce talent, organizations are finding it increasingly important to accurately assess their employees' potential; thus, they need to increase the validity and accuracy of such assessments (MacRae *et al.*, 2018; McDonnell and Skuza, 2022). The extant literature offers a vast and diverse list of factors that can be considered as possible components of potential, which might be useful for developing an assessment framework (Church *et al.*, 2015; Finkelstein *et al.*, 2018; MacRae *et al.*, 2018). Two early, large reviews of organizational practices (Silzer and Church, 2009, 2010) put together a list of factors that organizations often use to identify HP. These include leadership competencies, performance records, motivation to advance, results orientation, risk taking, adaptability/flexibility, experience, learning ability, commitment to the organization, personality and positive attitudes. It is noteworthy that the underlying model for determining potential has raised the assumption that employees who are perceived as HP generally have the capability to learn, grow and develop (McDonnell and Skuza, 2022; Meyers *et al.*, 2013).

Other scholars, such as Sparrow *et al.* (2015), who have looked at HRM literature through the lens of talent and the concept of capital, have suggested that it is important to assess three perspectives: human capital (stock of competencies and knowledge, social and personality attributes); social capital (the sum of the resources that can be mobilized through membership in social networks) and reputational capital (for example, being known in one's network for getting things done). Similarly, previous work by Gratton and Ghoshal (2003) built a model of so-called personal human capital, which contained three elements: intellectual capital (knowledge, skills and expertise), social capital (structure and quality of relationship networks) and emotional capital (courage and resilience with regard to taking actions).

By combining these approaches, we can collate sufficient robust theoretical and empirical support for considering a multidimensional framework of employees' capital that encompasses human and social capital (the two most common features) and two other sources, namely, reputation and emotional or psychological capital.

First, human capital (HC), which encompasses the productive resources possessed by workers, overall refers to their knowledge, work experiences, skills and abilities, which are necessary for achieving superior performance (Dokko and Jiang, 2017; Järlström *et al.*, 2020). The literature provides empirical evidence of positive relations between HC and several employees' outcomes (e.g. future performance potential and career success) (Ballout, 2007; De Vos and Chambré, 2017; Spurk *et al.*, 2019).

Second, social capital (SC) encompasses the relationships between organizational members. It is based on the capacity of employees to create, transfer and leverage knowledge between internal (employees and managers) and external contacts. This can help improve working conditions and individual and organizational performance (Dokko and Jiang, 2017; Seibert *et al.*, 2017; Tamer *et al.*, 2014). The size and quality (trust) of the network of relationships built by one employee may be considered a form of capital in the sense that it can create a productive resource for accessing and facilitating employee performance. Trust is often mentioned as a key aspect of SC because it facilitates the functioning of the network, opens communication channels and promotes knowledge sharing. Empirical data suggest that it facilitates teamwork and collaboration (Tsai and Ghoshal, 1998) and improves employees' performance (Wang *et al.*, 2015).

Third, psychological capital (PC) has a multidimensional nature, and its four building blocks are hope, self-efficacy, optimism and resilience (Kauffeld and Spurk, 2022; Luthans *et al.*, 2007). Overall, there is a good amount of evidence to suggest that PC is linked to a number of individual and organizational outcomes, such as performance, citizenship behaviors and the quality of social connections (Kauffeld and Spurk, 2022; Tamer *et al.*, 2014). It is assumed that PC has incremental value beyond the two more traditional sources of HC and SC.

In summary, HC, SC and PC can influence performance and career progression (Greenhaus and Kossek, 2014; Kauffeld and Spurk, 2022). Furthermore, Xu *et al.* (2023) conclude that the three types of capital interact with each other and synergistically influence individual career development. According to the multiple regression analysis, PC has the biggest impact, then SC and HC. Other recent studies, for example, Huang *et al.* (2021) and Xu *et al.* (2022), found that when HC, PC and SC were added to the regression equation, the model increased its explanation power.

In line with previous studies, we predict the following set of hypotheses:

H1. HC is positively related to employees' PCA.

H2. SC is positively related to employees' PCA.

H3. PC is positively related to employees' PCA.

Fourth, a relevant stream of literature claims that career decisions are made within a social context and that personal reputation – that is, how others perceive us (Blickle *et al.*, 2011; Zinko *et al.*, 2017). According to Greenhaus and Kossek (2014), a professional career is built through a pattern of consistent behaviors, performance and work experiences that unfold throughout an employee's life in their organization. Employees who are perceived to be proficient and to have high levels of certain competencies and aptitudes will have a better chance of being promoted and achieving success in their careers (Laird *et al.*, 2013; Zinko and Rubin, 2015; Zinko *et al.*, 2017). According to Zinko *et al.* (2012, 2016), an employee's reputation capital (RC) is based on how consistently other people perceive them to act, which is mostly influenced by the results they get and the character and integrity they have shown.

Hence, we hypothesize the following:

H4. RC is positively related to employees' PCA.

Fifth, the literature on RC has referred to both HC and SC as antecedent variables. HC influences employee reputation based on the levels of knowledge, competencies and

achievements displayed by the employees; SC refers to the quality of employees' social interactions and the degree of control they wield over their social networks. Even though PC has gotten less attention, it is also likely related to employees' professional reputation because it affects how well they do their jobs, which is important to how others perceive them (Kauffeld and Spurk, 2022; Luthans *et al.*, 2007; Zinko *et al.*, 2012).

Furthermore, we focused on considering the HC, SC and PC as relevant antecedent factors of RC, i.e. the building of our reputation by relevant others, for the purpose of our study, the managers who mostly have a decision on who is promotable or not in the organization.

Therefore, we made the following hypothesis:

H5. HC, SC and PC are antecedent factors of RC.

H5a. HC is positively related to RC.

H5b. SC is positively related to RC.

H5c. PC is positively related to RC.

Finally, HRM/HRD literature pays special attention to the promotion process. This subject is an as yet incomplete area of academic research with regard to our understanding of antecedents and related variables (Claussen *et al.*, 2014; Jawahar and Ferris, 2011; Ren *et al.*, 2019; Seibert *et al.*, 2017). Promotion decisions tend to be driven by individuals' readiness to move to a higher job – what is referred to as promotability judgments. According to studies that have been done on these kinds of decisions (Ferris *et al.*, 1992; Gurbuz *et al.*, 2016; Sibunruang and Kawai, 2022), performance evaluations, organizational politics, potential assessments, reputation and interpersonal relationships are all important in making decisions.

In the organizational context, promotions signal career success. When individuals are perceived as being promotable, they are considered to possess the necessary capabilities for performing roles of higher responsibility in the future (Bagdadli and Gianecchini, 2019; Slizer and Borman, 2017). According to empirical research, elements like the relationship between manager and employee, challenging work opportunities, one's reputation, citizenship behaviors and political skills can all have a positive impact on career progression decisions (Blickle *et al.*, 2011; Gentry *et al.*, 2012; Seibert *et al.*, 2017).

The developmental perspective associated with the concept of career could be related to the notion of potential, since it should be based not only on an analysis of current performance but also on the capacity to perform well in the future, at a higher level and in jobs with a greater amount of responsibility (Collings *et al.*, 2017a; Collings and Mellahi, 2009). Furthermore, reputational capital can hinder or facilitate employees' career progression based on their social representation and the manner in which they make the most of their organizational political environment (Blickle *et al.*, 2011; Zinko *et al.*, 2012; Zinko and Rubin, 2015).

Hence, we propose the following hypothesis:

H6. RC mediates the association between human (H6a), social (H6b) and psychological (H6c) capital and employees' PCA.

Figure 1 illustrates the theoretical research model built to synthesize the above-mentioned variables and their effects, as well as the resulting hypotheses.

3. Method

3.1 Sample and data collection procedures

This cross-sectional study collected data through a survey in order to obtain the perceptions of relevant persons (line managers) regarding focal individuals' qualities of HC, SC, PC, RC and PCA judgments. One manager evaluated each focal individual. Our goal was to get a large and diverse sample of workers so that we could generalize our results to the Portuguese context.

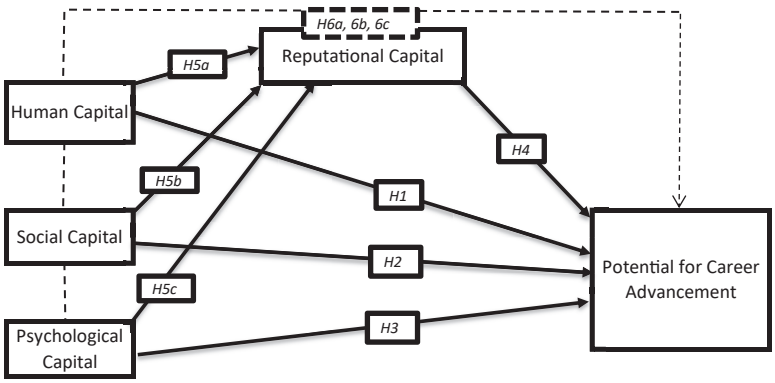


Figure 1.
Theoretical research model

Key: Dotted lines – mediation relations between variables
Source(s): Figure by authors

The sample was formed using two different approaches: first, we addressed 150 HR managers from medium- and large-sized private organizations from different economic sectors in Portugal through LinkedIn. This procedure ensures that only organizations with formal HRM practices are contacted. In 68 cases, those who accepted were asked to identify two or three qualified employees and send their line managers the link to the survey. Second, we gathered additional data from two other medium-sized firms with the assistance of the HR manager, who chose a group of employees and invited their managers to participate in the study.

The organization's workforce size ranged from 50 to 250 (62%), 250 to 1.000 (29%) and more than 1.000 (9%).

Our final sample included 384 valid individuals, excluding cases where the assessor had not worked for a minimum of one year with the focal person and the current performance was rated below average – consistent with our exclusive TM approach. This group had the following characteristics: knowledge workers in jobs requesting a degree or managers; an average age of 35.83 years (ranging from 20 to 55 years old) and 56% female and 44% male.

The survey utilized scales available in academic literature after making the necessary adjustments to reflect this study's objectives. We employed a conventional double-back translation strategy in which a qualified bilingual translator translated the original English items into Portuguese before translating them back into English. The variables were measured using a seven-point Likert-type scale: 1 ("totally disagree") to 7 ("totally agree").

3.2 Measures

Human capital (HC) – HC was assessed using two different measures: first, a five-item scale that Zinko *et al.* (2012) suggested using the concept of expertise. We slightly reworded the items in order to adapt them for use in more general contexts; two examples of items are "She/he is an expert at his/her job" and "She/he gives good technical suggestions." Second, we used the prospector, an instrument that McCall *et al.* (1994) developed. It measures employees' competencies and ability to learn from experience (Silzer and Borman, 2017) using 11 dimensions: seeks opportunities to learn, acts with integrity, adapts to cultural differences, is committed to making a difference, seeks broad business knowledge, brings out the best in people, is insightful, has the courage to take risks, seeks and uses feedback, learns from mistakes and is open to criticism. To control the survey length, we used only the operational description for each dimension.

Social capital (SC) – SC was measured based on two dimensions: the quality of relationships and the type and size of employees' contacts with relevant sources. The former is a six-item scale adapted from McAllister (1995), which covers both the cognitive and affective dimensions of interpersonal trust. Some examples of such items are as follows: "If I shared my problems with this person, I know (s)he would respond constructively and caringly" and "This person approaches his or her job with professionalism and dedication." The latter measures employees' social networks (Dokko and Jiang, 2017; Seibert *et al.*, 2017), and it includes their internal relationships with colleagues and managers – both in their own department and other areas of the organization – and external contacts (customers, suppliers and other organizations).

Psychological capital (PC) – PC was measured based on the four dimensions of the construct of psychological capital (PsyCap) developed by Luthans *et al.* (2007). To keep our questionnaire a reasonable length, we used only one operational description of each of the following dimensions: hope, efficacy, resilience and optimism.

Reputational capital (RC) – RC was measured using ten items from a 12-item scale that was originally developed by Hochwarter *et al.* (2007) and later used in a study by Zinko *et al.* (2012). The two deleted items were recommended in this latter study. A few examples are as follows: "This individual is regarded highly by others" and "This individual is regarded as someone who gets things done."

Potential for career advancement (PCA) – The measure of promotability was inspired by two proposals used in studies conducted by Jawahar and Ferris (2011) and Gurbuz *et al.* (2016). We used three items to reflect the criteria of ability, motivation and opportunity (along with the AMO theory in HRM, Day and O'Connor, 2017) to assess progress in a career. The items were as follows: "This person demonstrates the ability necessary for successfully performing jobs at a higher level of responsibility," "This person has the necessary ambition for successfully performing jobs at a higher level of responsibility" and "This person will progress (move up) in their career in this organization."

3.3 Control variables

Consistent with previous studies, we aimed to verify the potential influence of two demographic variables related to our sample: age and gender. Since no significant differences were identified in the sample, we excluded them from our data analysis.

3.4 Data analysis

We analyzed the study data using the structure equation modeling (SEM); we used SPSS and AMOS version 25 to conduct the analysis. The analysis was carried out in three phases. First, we tested each variable's measurement model. Second, we tested the proposed theoretical model's goodness-of-fit and compared it with alternative models, then tested our hypotheses. Third, we analyzed the mediating hypotheses, using the Sobel's test to examine the statistical significance of the indirect effects. This test is recommended for testing the significance of a mediation effect in SEM, which is the case with our RC variable. We used Hayes's macro-PROCESS version 4.0.2 (Hayes, 2022), which gives us percentile and bias-corrected bootstrap (5,000 bootstraps for percentile bootstrap confidence intervals) confidence intervals for drawing conclusions about indirect effects in models with a mediation component. We also used the Sobel test.

4. Results

4.1 Measurement model

The initial step consisted of performing confirmatory factor analysis (CFA) for the different measures that were part of the full model by using some of the most common fit indices,

comparative fit index (CFI), goodness of fit index (GFI), normed fit index (NFI) and root mean square error of approximation (RMSEA) to test the quality of the adjustment (Hair *et al.*, 2018). Additionally, we considered the χ^2/*df* ratio, ideally ranging from less than three to a maximum of five. All the measures exhibited overall acceptable properties (see Table 1). The factorial solutions revealed that for the measure of HC a second-order general factor that includes the scales of expertise and ability to learn; for SC, a second-order general factor that consists of interpersonal trust and social network; and for PC, RC and PCA, general factors based on the respective first-order indicators.

Furthermore, the descriptive statistics (means, standard deviations, alpha values and intercorrelations) for all the variables are shown in Table 2. The evidence supports the presence of good reliabilities (as measured by a Cronbach's alpha, with all of the cases exceeding the cut-off point of 0.70); furthermore, there was no evidence of possible constraints due to the non-normality of the multivariate data based on kurtosis and skewness, which were suggested to be close to 0 with no case of skewness >2 and kurtosis >7. However, since all the data came from the same respondents, the variance inflation factor (VIF) and tolerance were used to check for multicollinearity risks. The VIF scores were between 2.251 and 4.014 and the tolerance scores were between 0.249 and 0.397. These values were in line with what Hair *et al.* (2018) recommends.

Variables	χ^2	*df*	*p*	χ^2/df	NFI	CFI	GFI	RMSEA/ICLO
Human capital – two factors a)	183.692	92	0.000	1.997	0.939	0.969	0.951	0.049/0.038
Social capital – two factors b)	74.574	28	0.000	2.663	0.964	0.977	0.967	0.063/0.046
Psychological capital – four factors c)	7.762	2	0.021	3.881	0.988	0.991	0.991	0.083/0.038
Reputational capital – ten factors d)	82.247	27	0.000	3.046	0.973	0.965	0.965	0.070/0.053
Potential for career advancement – three factors e)	3.306	2	0.191	1.653	0.991	0.995	0.995	0.039/0.000

Note(s): a) This factor solution is based on a second-order general factor that includes the scales of expertise and ability to learn
b) This factor solution is based on a second-order general factor that includes the scales of interpersonal trust and social network
c) This factor solution is based on a general factor comprising four first-order factors
d) This factor solution is based on a general factor comprising ten first-order factors
e) This factor solution is based on a general factor comprising three first-order factors
Source(s): Table by the author

Table 1.
Evaluation of measurement models for the constructs used in the study

Variables	Mean	SD	1	2	3	4	5
Human capital – two factors	5.01	0.68	(0.83)				
Social capital – two factors	5.09	0.73	0.81	(0.72)			
Psychological capital – four factors	4.97	0.81	0.72	0.68	(0.83)		
Reputational capital – ten factors	5.19	0.79	0.80	0.81	0.74	(0.94)	
Potential for career advancement – three factors	4.94	0.87	0.64	0.56	0.67	0.64	(0.79)

Note(s): Internal consistency reliabilities are in parentheses along the diagonal. All correlations are significant at the 0.01 level (two-tailed)
Source(s): Table by the author

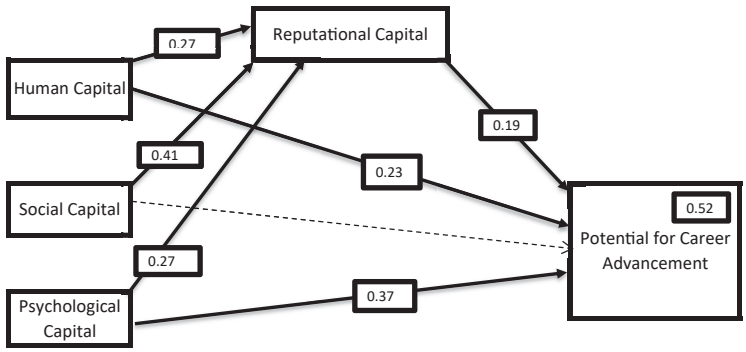
Table 2.
Descriptive statistics and correlations for the constructs used in the study

4.2 Structural models

An SEM methodology was used for testing the theoretical research model (Figure 1) and the associated hypotheses. We analyzed the theoretical research model (where all paths relating to the constructs were estimated). This model did not show acceptable adjustment indices, CFI, GFI, NFI and RMSEA below the recommended threshold values. In order to get a better adjustment for the research model, the data analysis suggested deleting the effect of SC on PCA (Figure 2). This updated model displays excellent fit indices, namely CFI, GFI and NFI above 0.95 and RMSEA below 0.05. Furthermore, the three alternative models that were used for comparison against this baseline model displayed much worse fit indices (Table 3). These models were as follows: (1) the four factors of personal capital with independent effects on PCA; (2) HC, SC and PC forming a latent common factor with a mediated effect on PCA through RC and (3) the four factors of personal capital forming a common latent factor with a direct effect on PCA. Accordingly, we proceeded with all further analyses (hypotheses and overall model) based on the adjusted theoretical model (see Figure 2, which illustrates the path model and the measurement results with the standardized path coefficients and the adjusted R^2 values).

4.3 Hypothesis testing

The findings show that the theoretical model explained 52% of the PCA judgments. Moreover, all four types of personal capital – human, social, psychological and reputational – had a direct and/or indirect effect that was important and meaningful.



Key: Dotted lines – nonsignificant relation between variables
Source(s): Figure by authors

Figure 2. Updated theoretical model

Structural models	χ^2	*df*	*p*	χ^2/df	NFI	CFI	GFI	RMSEA
Updated theoretical model	1.580	1	0.209	1.580	0.994	0.998	0.998	0.037
Alternative Model 1 a)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Alternative Model 2 b)	41.447	4	0.000	10.362	0.837	0.847	0.952	0.149
Alternative Model 3 c)	41.821	5	0.000	8.364	0.836	0.850	0.951	0.132

Note(s): a) the four factors of personal capital with independent effects on PCA
b) HC, SC and PC forming a latent common factor with a mediated effect on PCA through RC
c) The four factors of personal capital forming a common latent factor with a direct effect on PCA and, n.a. – not adjusted
Source(s): Table by the author

Table 3. Fit indices for structural models

All the hypotheses, with one exception, were confirmed, thus providing support for the relevance of the four personal capital sources in forming managers' perceptions of employees' potential for career advancement.

There was only one case that did not show a significant direct effect on our endogenous variable (PCA), and that was SC (despite its moderate-high correlation of 0.56). Two of the three partial mediation effects foreseen by the theoretical model were confirmed. The only one that did not occur was the effect of SC over RC with regard to PCA (H6 b). On the other hand, the study findings confirmed the partial mediation effect of RC over HC and PC, which effects employees' PCA (H6 a) and H6 c) (see the Sobel tests presented below).

a) HC - RC - Employees' PCA

	$(a \cdot b) =$	0,074
Sobel Test	$\sqrt{[(a \cdot SEb)^2 + (b \cdot SEa)^2]} =$	**0,032**
	$Z =$	2,330
	$p =$	**0,020**
	$(\beta_a \cdot \beta_b) =$	0,051
	Proportion of (X → Y) due to M $(c - c')/c =$	**18,1%**

b) PC - RC - Employees' PCA

	$(a \cdot b) =$	0,054
Sobel Test	$\sqrt{[(a \cdot SEb)^2 + (b \cdot SEa)^2]} =$	**0,023**
	$Z =$	2,358
	$p =$	**0,018**
	$(\beta_a \cdot \beta_b) =$	0,051
	Proportion of (X → Y) due to M $(c - c')/c =$	**12,3%**

Our results also demonstrate that, when considering the effects on RC, the dominant effect is of SC, $\beta = 0.41$, while the other two variables, HC and PC, exhibit equal effects of $\beta = 0.27$. On the whole, these three variables explain 75% of RC. However, when the target variable is the PCA, we see significant direct effects from HC, $\beta = 0.23$, PC, $\beta = 0.37$ and RC, $\beta = 0.19$.

5. Discussion

5.1 General conclusions and theoretical implications

One fundamental research question and two main objectives served as the study's guiding principles. To start, its main goal was to add to the existing theoretical and empirical evidence on two major topics in HRM/HRD literature: the "what" and "how" of using the TM process to give companies a competitive edge (Claussen *et al.*, 2014; McDonnell *et al.*, 2017; Ren *et al.*, 2019). Thus, using the perspective of TM, we have highlighted the need for stronger theoretical frameworks and more effective assessment models of talent (Lacey and Groves, 2021; McDonnell and Skuza, 2022).

First, the current study aimed to improve understanding of the role of HR practices in applied studies on TM, specifically employee potential assessment and career management. One key focus area is the search for ways to improve decision makers' ability to make informed decisions on TM issues so that organizations can maximize their investments in HC (Kravariti and Johnston, 2020; Robledo-Ardila and Román-Calderón, 2022). Criteria used by organizations to determine the so-called HP (Crowley-Henry *et al.*, 2019; Silzer and Church, 2010) play an important role in these decisions.

Second, it is derived from a research perspective that seeks to explore a definition of talent based on the concept of employees' capital. Gratton and Ghoshal (2003), Luthans *et al.* (2007), Sparrow *et al.* (2015) and Zinko *et al.* (2016), among others, have looked at different sources of human, social, and emotional or psychological capital as important predictors of employees' career advancement and success.

Considering these aims, our study adopted and tested a model that describes and measures employees' capital from a multidimensional perspective – that is, by including four capital sources: HC (what you know); SC (whom you know); PC (who you are) and RC (how others perceive us). Our findings support the existence of a positive and significant influence from these four sources on the assessment of career advancement potential. This evidence reinforces previous arguments for the use of multidimensional models, which are closely related to a more holistic view of potential (Cascio *et al.*, 2017; Sparrow *et al.*, 2015).

We contend that our theoretical contribution is a threefold.

First, our results make an important contribution to the study of what causes employees' PCA and help to clarify the decision criteria used to find HP employees (Jawahar and Ferris, 2011; Robledo-Ardila and Román-Calderón, 2022). By doing so, our study expands current knowledge by focusing on one particular sub-system of HRM, high potential identification, contributing to what Storey *et al.* (2019) claimed to be the need to have studies focused on "HR targeting practices."

Second, by finding the connections between the human, social, psychological and reputational capital sources of employees, we broaden the debate about what makes someone talented and what gets them promoted. Our results add to what other studies (Huang *et al.*, 2021; Xu *et al.*, 2022, 2023) have found about how three types of employee capital – HC, SC and PC – affect career development and job performance in the field of TM. In particular, they fill in the gaps about their relevance in identifying the potential for career advancement.

Third, the findings regarding personal reputation's role as a source of employees' capital may be useful for expanding the conceptual debate about its nature, thus highlighting both its "hard" roots (knowledge, skills and other attributes) and a more "relational" view. It is very illuminating to understand this double facet of reputation, especially considering that HC and PC combined have a greater influence than SC in forming managers' perceptions of employees' reputation. Therefore, personal reputation is a valid and useful construct when it comes to managing talent. Therefore, we put forward conceptual and empirical evidence to clear up the construct as well as rule out the risk of its subjective nature.

5.2 Managerial implications

From a management point of view, the results of this study may be of interest to organizational leaders who are looking for ways to get the most out of their TM policies and practices to improve business performance and gain a competitive edge (Crowley-Henry *et al.*, 2019). Also, these results may help organizations look at their current criteria for including people in the HP pool and link management tools in use to the four types of capital that employees have.

Another important suggestion for organizational leaders is the fact that these findings could also help to clarify that assessing PCA is a complex, multidimensional phenomenon that should encompass a variety of criteria (Finkelstein *et al.*, 2018; Skuza *et al.*, 2021).

This study emphasizes the technical and social nature of this process and supports personal reputation as a valid core component, minimizing its conceptual and empirical overlap with impression management tactics. It also shows how each source of employees' capital affects career outcomes in a unique way when integrated into a common framework, as they often do in organizations.

In addition, our study may be of interest to HR managers who want to strengthen their strategic roles. Boudreau and Ramstad (2005) say that this effort will be an important step in maximizing the contribution of the HR function to organizational decision-making and performance.

Furthermore, the study can benefit the underlying transparency of this critical HRM process by bringing the perception of fairness to the forefront of this management decision. By doing so, we can have the expectation that society will be better able to create the right opportunities for people to achieve their potential and also make the best use of collective human capital.

5.3 Limitations and suggestions for future research

We must emphasize that, despite the substantial effects of our four predictors – HC, SC, PC and RC – in explaining judgments regarding employees' PCA (52% of variance), we strongly recommend that future research use the necessary caution in the interpretation of results, especially with regard to the causal model that is tested in the theoretical research model. Given our use of cross-sectional data, no causal inferences could be made with regard to the relationships in this study, although the relationships depicted in our research model were based on a sound theoretical framework – that is, capital as productive resources. So, any future research studies that use a longitudinal design will help the field by looking at how being considered for a promotion at a certain point in time can really help employees move up in the organization faster and higher than others.

Another study limitation could be attributed to our data collection method and its potential for bias; additionally, even though we exercised caution by collecting data from an external assessor (line managers), we were unable to completely eliminate bias. In the future, researchers could look into a variety of assessors.

Third, regarding this study's utilized measures, we suggest some caution in considering the psychological capital scale because, due to the length of our questionnaire, we opted to use an operationalization based on the four dimensions definition; thus, we are not testing the PsyCap inventory.

Finally, using a profile method analysis, it would be interesting to closely examine the dynamics between the four personal capital sources.

6. Conclusion

The current study contributes some novel ideas to the talent management theory and practice, particularly in the context of talent pools. It is the only empirical study to date that has looked at the combined impact of HC, SC, PC and RC on employee assessment of their potential for career advancement. Our findings also contribute to a better understanding of the underlying mechanisms of reputational capital and show how it mediates the effects of HC, SC and PC on PCA. It also emphasizes the significance of focusing on what Luthans *et al.* (2007) defined as a synergistic integration of human, social and psychological capital in order to realize human potential. Finally, the study sheds light on an important empirical question: what is the optimal combination of key characteristics of high-potential employees? Skuza *et al.* (2021).

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Organizational justice, supervisor-provided resources and duty orientation: lessons from the mining sector

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Abstract

Purpose – The study analysed the influence of organizational justice on the duty orientation of employees in the mining sector of Ghana. Also, it examined the mediating role of supervisor-provided resources in the relationship between organizational justice and duty orientation.

Design/methodology/approach – The study obtained data through a self-administered questionnaire from 291 employees of a mining firm. The data were analysed and interpreted in light of the hypotheses using the partial least squares structural equation modelling technique.

Findings – The findings revealed that organizational justice had a significant positive relationship with duty orientation and supervisor-provided resources. The results again established that supervisor-provided resources had a significant positive relationship with duty orientation. The study finally documented that supervisor-provided resources partially mediate the relationship between organizational justice and duty orientation.

Practical implications – We recommended that the management of the mining companies devote resources to developing organizational justice policies based on fairness in resource allocation, clear roles, employee feedback and effective information dissemination. Furthermore, supervisors should place priority on acquiring and dispensing resources as employees demonstrate their willingness to improve duty orientation.

Originality/value – The study contributes to knowledge in a novel research area. It adds to empirical evidence by highlighting the possible variables that may influence employees to engage in duty orientation.

Keywords Organizational justice, Supervisor-provided resources, Duty orientation, Mining sector

Paper type Research paper

Introduction

The mining sector is one of the key areas that makes significant contributions to the development of the Ghanaian economy. Data from the Ghana Revenue Authority (GRA) shows that total direct domestic fiscal receipts attributable to the mining and quarrying sector improved from GH₵ 2.36bn in 2018 to GH₵ 4.02bn in 2019. The 70% increase in fiscal payments by firms in the sector was occasioned by the simultaneous increase in production

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and price, particularly gold. Specifically, corporate tax receipts from the minerals sector increased by 89% to GH₵ 2.27bn in 2019 from GH₵ 1.20bn in 2018. Consequently, the firms in the sector are expected to operate within the legal framework of environmental and societal consciousness to reap business prosperity. The Environmental Protection Agency Act, 1994 (Act 490) of Ghana enjoins firms in the sector to proactively train and equip employees on environmentally friendly ways of operating.

While businesses in the mining sector may rely on multiple approaches to excel in terms of addressing regulatory and societal needs and making profit (Blinova *et al.*, 2022; Sauer and Hiete, 2019), the presence of employees who are willing to exceed the formal responsibilities specified in their job descriptions has been acknowledged by scholars as a rare resource that can help these organizations succeed (Ansong *et al.*, 2022; Hannah *et al.*, 2014). These employees possess a bundle of discretionary behaviours that are critical for building the goodwill of organizations and spurring productivity (Gnankob *et al.*, 2022). Following the different conceptualizations of discretionary behaviours such as extra-role behaviour (Singh and Singh, 2019), contextual performance and organizational citizenship behaviour (OCB) (Organ, 1994), the present study relied on the construct of duty orientation, which Hannah *et al.* (2014) argued to be the higher order of discretionary employee behaviours. The authors described duty orientation as one's volition to serve and faithfully support other members of the group, to strive and sacrifice to accomplish the tasks and missions of the group and to honour its codes and principles. Evidence supports the fact that duty orientation can be an important resource to improve organizational performance in complex work environments like the mining sector that demand team-oriented work practices (Ansong *et al.*, 2022; Eva *et al.*, 2020). Apparently, employees in the sector who possess these rare traits of duty orientation tend to project their organizations as meeting the lawful demands of the sector (Ansong *et al.*, 2022). As Moss *et al.* (2020) submitted, individuals with a higher duty orientation towards their group are motivated to serve the best interests of coworkers, fulfil their shared mission and align with the group's norms to improve overall performance.

Based on extant literature, organizational justice is a key determinant of extra-role behaviours such as duty orientation and related constructs such as satisfaction and commitment (Akram *et al.*, 2020). Broadly, organizational justice connotes the degree to which employees perceive the "procedural, distributive, interactive and informative" actions or decisions of their organizations as being fair to all members (Hoang *et al.*, 2022; Le *et al.*, 2021). Procedural justice refers to the individual's perception of the fairness of procedural elements within a social system that regulate the allocation of resources (De Clercq *et al.*, 2021). Distributive justice denotes the perceived fairness of the outcomes received by an employee (Pan *et al.*, 2018). Interactional justice emphasises how decision-makers treat others with dignity and provide reasonable justification for the decision being made (Kurdoglu, 2020). Likewise, informational justice focuses on the explanations provided to employees that convey information about why certain procedures were used in a certain way or outcomes were administered (Kurian and Nafukho, 2022). This suggests that organizational justice captures what the employees see as fair treatment received from organizational authorities in discharge of their roles (Terpstra and van Wijck, 2023).

Thus, Moss *et al.* (2020) claimed that since duty orientation is about the individual's volitional decision to make self-sacrifices, they may portray these traits if they perceive fair and reasonable treatment from members. Consistent with the social exchange theory (SET), Blau (1964) argued that interactions are interdependent or contingent on the actions of social exchange partners, in which recipient parties reciprocate with good where good was done to them. Following theory's tenets, Stafford and Kuiper (2021) advanced that a proposed social exchange between leaders and members would have to be equivalent to balancing reciprocity. Therefore, it is possible that employees will exhibit duty orientation to

compensate their organizations when they feel that they are being fairly and reasonably treated. Judging also from the perspective of organizational justice theory (Colquitt, 2001), the present study sought to share a similar view that employees would be driven to demonstrate duty orientation based on managers' traits of justice, fairness and equity. In other words, with a sense of organizational justice (Asif *et al.*, 2019), the employees may be pleased with management's actions and decisions, which eventually could propel their willingness to perform beyond their scope of work.

Despite attempts to link organizational justice to discretionary behaviours, limited attention has been given to the concept of duty orientation. Recent works have focused on how leadership (Ansong *et al.*, 2022; Moss *et al.*, 2020), perceived organizational support (DeConinck *et al.*, 2021; Eva *et al.*, 2020) and ethical psychological climate (Gok *et al.*, 2023) influenced duty orientation, with a dearth of literature on the role of organizational justice. Meanwhile, organizational justice encompasses a series of organizational actions that eschew discrimination, information asymmetry and the unfair allocation of resources for work. Thus, the lack of studies on how it drives duty orientation within the mining sector of Ghana calls for further investigation. This is because literature (Khaola and Rambe, 2021) is reluctant to accept the transportation of Western-designed studies into developing contexts without comprehensive analysis of their relevance in such contexts. In addition, organizational justice studies recently (Aggarwal *et al.*, 2022; Akram *et al.*, 2020; Jehanzeb and Mohanty, 2020) advocated for broader contextual investigations that could include plausible intervening variables to comprehend how the construct can transmit indirect influence on employees' extra work behaviours. Such interventions are essential for illuminating the different mechanisms through which organizational justice affects employee outcomes (Khaola and Rambe, 2021).

We anticipate that supervisor-provided resources (SPR), which describes the tangible and intangible resources supervisors provide employees to facilitate work delivery (Akram *et al.*, 2020; Rabbani *et al.*, 2017; Lemmon *et al.*, 2016), is a potential mediator in the link between organizational justice and duty orientation. By providing the employees with such unique resources as love, care and equitable pay recommendations, the supervisors convey positive signals to the employees to demonstrate duty orientation (Lemmon *et al.*, 2016). According to Lemmon *et al.* (2016), employees see things that assist them in the performance of their work as good resources, and when the same are provided by supervisors, they produce desirable employee outcomes. Supervisors are the "human face" of organizations who yield more influence in decision-making concerning resource allocation and the fairness of the same is reflected in the practice of organizational justice (Rabbani *et al.*, 2017). Therefore, when mining firms uphold organizational justice, their supervisors may follow a similar tune, which could translate into employees' self-sacrificing behaviours like duty orientation.

The study contributes to the literature in many prominent ways. The study attempts to fill the gaps on calls to evaluate incremental factors through which organizational justice stimulates employees' extra-role behaviours (Akram *et al.*, 2020; Jehanzeb and Mohanty, 2020). By understanding how SPR mediates the link between the primary constructs, practitioners are resourced with knowledge relating to factors through which duty orientation could be enhanced. Managers of the mining firms will be enlightened to formulate appropriate policies to help groom employees to be duty-orientated to activate the overall organizational performance. The results of the study would also guide employers in their recruitment and selection initiatives by selecting applicants who are predisposed to exhibiting the attributes of duty orientation. The study would encourage supervisors to be fair and just in dealing with employees. Theoretically, it would contribute to the existing literature on how organizational justice improves employees' duty orientation through SPR interventions.

Literature review and hypotheses development

Organizational justice and duty orientation

Drawing from the social exchange (Blau, 1964) and organizational justice (Greenberg, 1987) theories, which suggest employees react to conditions created by organizations, the employees will demonstrate duty orientation as a beneficial social exchange when employers care about their interests in a manner that is fair and acceptable (Canet-Giner *et al.*, 2020). To amplify this assertion, Ruiz-Palomino *et al.* (2023) claimed that supervisors who appear as ethical leaders by demonstrating integrity, fairness, altruism and concern for the needs of subordinates tend to motivate the employees to exhibit unspoken behaviours such as customer orientation. By shaping an ethical climate, the employees, within the spirit of reciprocity, are inclined to perform duty orientation (Mkheimer *et al.*, 2023; Ruiz-Palomino *et al.*, 2023; Stafford and Kuiper, 2021). Other scholars that have investigated the link between organizational justice and some duty orientation-related concepts such as work innovative behaviour, ethical behaviour, organizational citizenship behaviour, employee commitment and extra-role performance have reported positive associations (Al Halbusi *et al.*, 2021; Akram *et al.*, 2020).

For instance, Imamoglu *et al.* (2019) analysed survey data from 211 respondents across 101 firms and found that organizational justice has a positive and significant effect on both organizational commitment and firm performance. Similarly, Al Halbusi *et al.* (2021) documented that each of the dimensions of organizational justice (procedural, distributive, interpersonal and informational) correlated with ethical behaviour. This leads us to anticipate that when management shows organizational justice, employee may reciprocate duty orientation. Hence;

H1. Organizational justice has significant positive relationship with duty orientation.

Organizational justice and supervisor-provided resources

Lemmon *et al.* (2016) described supervisor-provided resources to capture intangible attributes such as care, love, recognition and fairness offered by superiors in the workplace beyond tangible resources. These resources are categorized to include informational resources (supervisor's work-related communication, including facts, opinions, oral or written communication, conveyed verbally and/or behaviourally); love and status resources (love is an employee's perception of his or her supervisor's warmth, caring, or friendship towards the employee, whereas status is an employee's perception of the supervisor's admiration of the focal employee); and money (defined as an economic benefit, e.g. pay raises, bonuses accrued by virtue of the employee's supervisor). Thus, SPR is a sort of psychological assistance that "love" employees immediately receive from their supervisor(s) to help complete a work assignment (Lemmon *et al.*, 2016).

O'Connor and Crowley-Henry (2019) emphasised that organizational justice is hinged on the perceptions held by employees concerning subjective fairness in their employment relationships. Thus, it appears attributes of SPR overlap with organizational justice in the event that when organization through their supervisors, provide equitable resources, these will be interpreted by employees as the fulcrum of justice in such a setting (Hameed *et al.*, 2019), which may positively influence the availability of SPR to employees. Hence, the study proposed that:

H2. Organizational justice has significant positive relationship with supervisor-provided resources.

Supervisor-provided resources and duty orientation

In line with the SET, Maan *et al.* (2020) submitted that organizations that support their employees tend to increase the norms of reciprocity. This implies that employees in such

organizations feel more indebted to these entities and may have a higher propensity to demonstrate duty orientation. According to Ahmad and Zafar (2018), employees' fulfilment of instrumental and socioemotional expectations enhances their positive judgements about employers, triggering behaviours such as demonstrating high attendance, taking proactive approaches to organizational challenges, supporting their colleagues and working beyond their legal work requirements. Accordingly, Talukder *et al.* (2018) revealed that supervisory support was key to enhancing employee performance because supervisors assist employees in attaining work–life balance. Also, Zagenczyk *et al.* (2021) confirmed a positive relationship between perceived organizational support and affective organizational commitment.

Although there have not been specific studies on how SPR influence duty orientation, we rely on the aforementioned empirical evidence on the positive relationship between perceived organizational support and positive work behaviours related to duty orientation to project a likely association between the variables. This is because, as employees develop the feeling that their supervisors can reach out to them in terms of need, such feelings could be translated into duty orientation. Therefore, we propose that:

H3. Supervisor-provided resource has significant positive relationship with employee duty orientation.

Organizational justice, supervisor-provided resources and duty orientation

Despite the fact that previous studies suggest facets of organizational support could stimulate positive work behaviour such as duty orientation (Baafi *et al.*, 2021; Imamoglu *et al.*, 2019; Akram *et al.*, 2020; Singh and Singh, 2019), the role that SPR plays in the relationship between organizational justice and duty orientation has not been given attention. Following the earlier arguments and the research evidence provided for hypotheses 2 and 3, the study anticipates that organizational justice could influence SPR, which may in turn positively affect employees' duty orientation. Consistent with the organizational justice theory, the study argues that organizations that make their systems and procedures fair and honest will get the employees to believe that their supervisors are providing resources in the form of championing support for their needs. In light of the tenets of reciprocity (Blau, 1964), these practices will culminate in duty orientation. Through justice perceptions, the employees' resource loss is minimized (Hobfoll and Freedy, 2017) and, to that extent, their morale in conducting their duties. Hence, we propose that SPR could serve as a mediator in transmitting the indirect effects of organizational justice to duty orientation. Based on the arguments advanced, we hypothesise that:

H4. Supervisor-provided resource mediates the relationship between organizational justice and duty orientation.

Conceptual framework

The framework (see Appendix A) shows the interrelationships among the variables under study. Duty orientation is the dependent variable of the study and organizational justice is the independent variable. SPR serve as the mediating variable, as already established in the literature. According to the framework, organizational justice could have a direct and indirect link with duty orientation through SPR.

Methodology

Around 291 out of a total of 1,200 employees were drawn from a mining company operating in the Ashanti Region of Ghana for the study. The company selected is one of the largest mining firms in the region and across the country. This fits the premises on which it was selected,

besides the fact that the Ashanti Region of Ghana is where the majority of the mining firms are cited. By relying on Krejcie and Morgan's (1970) sample size determination technique, the study concluded that the sample size used was representative of the total population of 1,200 employees from the mining company. The study further deployed the simple random sampling procedure to identify the respondents for the study, primarily to defeat the issues of sampling bias in the study. Also, a structured self-administered questionnaire was used to collect the data by distributing the questionnaires to the sampled employees during working hours between July and August 2021 on a face-to-face basis. Out of the 291 questionnaires that were distributed, it turned out that the majority of the respondents were males as opposed to females in percentage terms of 64.6% and 35.4%, respectively. In terms of their age groups, 68.4% of them, who were the majority, were between the ages of 31–45 years, while 19.6% of them were between the ages of 18–30 years 10.7% were between the ages of 46–60 years and 1.4% were above 60 years. Finally, the respondents' characteristics in respect of work experience indicated that 37.1% of the respondents have worked for the company for over nine years. This was followed by 25.8% of the respondents who indicated that they had worked for less than two years. Furthermore, 25.8% of them indicated that they have been working in the company for about 6–8 years, while 12.7% said that they have been working for about 3–5 years. The background of the respondents was presented in Appendix B.

Measures

The scales used in the study were adopted from empirically validated instruments by previous scholars of the constructs. Organizational justice is madeup of four-subscales, comprising procedural, distributive, interactive and informational justice. The scale was adopted from a study conducted by Colquitt (2001) due to its wide usage. SPR scale comprising items on love, status and money, developed and validated by Lemmon *et al.* (2016), was used to elicit responses from the participants. With respect to duty orientation, the study deployed the 12-item instrument developed and validated by Hannah *et al.* (2014). The instrument captured three subconstructs, including respondents' extra role of feeling duty to members of their organization, to their organization's mission and to their organization's morals and codes. The items for the various instruments have been placed in Appendix C for reference.

Analysis

The data were analysed using the partial least square structural equation modelling (PLS-SEM) technique from SmartPLS version 4.0.9.2. PLS-SEM has been praised for its robustness in the determination of relationships among constructs in complex research models (Ringle *et al.*, 2020). It is also effective when analysing data involving higher-order constructs (HOC). The HOC improve the model parsimony and allow for analysis of dimension-specific effects on subsequent constructs (Ringle *et al.*, 2020; Wong, 2019). Because the analysis was based on HOC approach, it was worthwhile leveraging the efficacy of PLS-SEM to interpret the results. Thus, the subconstructs (i.e. procedural justice, distributive justice, interactional justice and informational justice) were used as lower-level constructs (LOC) of the HOC, organizational justice (see Appendix D).

Methodologically, the LOCs are first examined through the PLS-SEM algorithm to ensure the subconstructs have appropriate loadings and correlations with the HOC and then, the HOC is connected to the endogenous (dependent) variable. Again, when assessing the roles of incremental or intervening variables like mediators in the relationship between exogenous and endogenous variables, the PLS-SEM approach seems appropriate (Sarstedt *et al.*, 2021). SPR construct were used as a mediator in the current study. Consequently, the study

evaluated the measurement model through indicator or outer loadings, internal consistency and discriminant validity of the constructs. Next, the structural model follows the prescribed indices comprising correlation coefficients or paths (R), coefficient of determination (R^2), predictive relevance (Q^2), effect size (f^2) and a significant level of 5% or less or a t-statistic of 1.96 or higher to test the structural model (Hair *et al.*, 2019).

Results

Measurement model

The results in Tables 1 and 2 present insights on the assessment of the indicator and constructs' reliability for the model. According to Table 1, indicator reliability, which shows the proportion of variance of an indicator that can be described by its underlying latent variable (Ong and Puteh, 2017), was assessed using the loadings. The results suggest that the indicators have met the 0.60 or higher threshold for social research (Hair *et al.*, 2019).

Also, the internal consistency test for the constructs was not violated. As a rule of thumb, by establishing the cut-off points of CA, rho_A and CR at values > 0.70, it could be deduced that all the scores for the constructs were >0.70. Furthermore, the convergent validity (CV) of the study based on the average variance extracted (AVE) score is presented in Table 2. The rule of thumb is that all the AVE scores should have a minimum threshold of ≥0.50 for each construct (Hair *et al.*, 2019). A cursory look at the scores of the major constructs, including the dimensions of organizational justice, in Table 1 revealed that the constructs have met the criteria (AVE scores ≥0.50).

We assessed the discriminant validity of the model to ascertain the uniqueness of each construct employed in the study using the HTMT ratio results captured in Table 2. Theoretically, the HTMT ratio shows superior performance by having the ability to detect discriminant validity in more common research scenarios than other techniques (Henseler *et al.*, 2016). The rule of thumb is that to achieve DV, HTMT values should be < 0.85 for unrelated constructs or <0.90 for research scenarios where the constructs are highly related (Hair *et al.*, 2019). Given that the study relied on the HOC approach, in which the LOCs are related by dimensionality, the present study used the 0.90 as a benchmark for testing issues of discriminant validity. From Table 2, all the values for each of the constructs and subconstructs were below HTMT.90. This is a good indication that each construct is truly distinct from the others. After these basic assessments, the study followed up with the analysis of the research hypotheses in Table 3.

Structural model

After a successful evaluation of the constructs quality criteria through the measurement model, the structural model results were followed. The results of the structural model, as reported in Table 3, formed the basis for testing the research hypotheses postulated.

By checking the results of the lower-lever constructs in Table 3, it can be expressed that the four subconstructs (procedural, distributive, interactive and informational) effectively form and contribute to the organizational justice construct. This is reflected in the R^2 value of 0.999 (see also Appendix D). Furthermore, the results in Table 3 are in line with the study's expectations imitated in the hypotheses. It can be seen that organizational justice has a significant positive relationship with duty orientation ($R = 0.450$; $t = 6.894$; $p < 0.001$) and SPR ($R = 0.634$; $t = 12.824$; $p < 0.000$). Also, the results indicate that SPR had a significant positive relationship with duty orientation ($R = 0.162$; $t = 2.017$; $p = 0.044$). Finally, the results reported in the indirect column of Table 3 were consistent with the study's hypothesis that SPR partially mediates the relationship between organizational justice and duty orientation ($R = 0.103$; $t = 1.968$; $p = 0.041$).

Constructs/Items	Loadings	CA	rho_A	CR	CV (AVE)
Organizational justice		0.959	0.962	0.963	0.544
OJD10	0.728				
OJD11	0.790				
OJD7	0.509				
OJD8	0.654				
OJD9	0.697				
OJI12	0.843				
OJI13	0.825				
OJI14	0.836				
OJI15	0.796				
OJIF16	0.841				
OJIF17	0.790				
OJIF18	0.849				
OJIF19	0.787				
OJIF20	0.811				
OJIF21	0.622				
OJIF22	0.592				
OJP1	0.708				
OJP2	0.729				
OJP3	0.662				
OJP4	0.677				
OJP5	0.664				
OJP6	0.698				
Duty orientation		0.958	0.960	0.964	0.748
DTO10	0.845				
DTO11	0.857				
DTO2	0.855				
DTO3	0.843				
DTO5	0.853				
DTO6	0.897				
DTO7	0.894				
DTO8	0.895				
DTO9	0.841				
Informational justice		0.926	0.937	0.941	0.698
OJIF16	0.866				
OJIF17	0.863				
OJIF18	0.917				
OJIF19	0.888				
OJIF20	0.897				
OJIF21	0.707				
OJIF22	0.678				
Interactive justice		0.939	0.941	0.956	0.845
OJI12	0.941				
OJI13	0.938				
OJI14	0.939				
OJI15	0.836				
Distributive justice		0.934	0.935	0.953	0.836
OJD10	0.943				
OJD11	0.860				
OJD8	0.928				
OJD9	0.944				
Procedural justice		0.959	0.960	0.967	0.831
OJP1	0.889				
OJP2	0.907				

Table 1.
Assessment of items reliability, internal consistency and convergent validity

(*continued*)

Constructs/Items	Loadings	CA	rho_A	CR	CV (AVE)
OJP3	0.898				
OJP4	0.925				
OJP5	0.934				
OJP6	0.917				
Supervisor-provided resources		0.932	0.941	0.944	0.680
SPR1	0.811				
SPR2	0.853				
SPR3	0.894				
SPR4	0.912				
SPR5	0.876				
SPR6	0.838				
SPR7	0.688				
SPR8	0.695				

Note(s): CA – Cronbach's alpha; CR – Composite reliability; CV – Convergent validity and AVE – Average variance extracted
Source(s): Table by authors

Table 1.

Constructs	1	2	3	4	5	6	7
1. Duty orientation							
2. Informational justice	0.509						
3. Interactional justice	0.431	0.696					
4. Distributive justice	0.509	0.861	0.857				
5. Organizational justice	0.573	0.651	0.822	0.843			
6. Procedural justice	0.482	0.582	0.363	0.547	0.807		
7. Supervisor-provided resources	0.469	0.761	0.449	0.514	0.659	0.455	

Note(s): DO – Duty orientation; IJ – Informational justice; ItJ – Interactive justice; DJ – Distributive justice; PJ – Procedural justice and SPR – Supervisor-provided resource
Source(s): Table by authors

Table 2.
Discriminant validity through the HTMT ratio

Structural path	(β)	*t*-stats	*p*-values	Hypotheses	R^2	Q^2	f^2
OJ					0.999		
DO					0.322	0.233	
SPR					0.402	0.267	
LOCs							
Procedural → OJ	0.347	18.268	0.000				
Distributive → OJ	0.218	21.034	0.000				
Interactive → OJ	0.229	18.489	0.000				
Informational → OJ	0.394	26.140	0.000				
Direct (HOC)							
OJ → DO	0.450	6.894	0.000	H1: Supported			0.179
OJ → SPR	0.634	12.824	0.000	H2: Supported			0.672
SPR → DO	0.162	2.017	0.044	H3: Supported			0.023
Indirect (mediation)							
OJ → SPR → DO	0.103	1.968	0.041	H4: Supported			

Note(s): "R^2 of 0.25, 0.5 and 0.75 is considered as weak, moderate and substantial respectively; Q^2 of 0.02, 0.15 and 0.35 is considered as small, medium and large, respectively; f^2 of 0.02, 0.15 and 0.35 is seen as small, medium and large, respectively"
Source(s): Table by authors

Table 3.
Hypotheses testing

On the basis of the R^2, the study asserts that organizational justice and SPR together explained 32.2% of changes in employees' duty orientation in organizations. Besides, organizational justice was to have accounted for 40.2% of variations in the scores of SPR. Finally, the predictive relevance of the PLS model along with the various effect sizes of the exogenous variables on the endogenous variable were satisfactory.

Discussion

The study investigated the influence of organizational justice on the duty orientation of employees in the mining sector of Ghana, using SPR as a mediator. The results of the study supported the hypotheses. Concisely, it was established that organizational justice has a significant positive influence on duty orientation and SPR. With organizational justice, we conclude that employees perceive the policies and systems of companies that are equitable and fair as important resources that facilitate the performance of their work. Again, organizations that eschew discrimination and bias are better positioned to spur duty orientation among their employees. Overall, the findings support the view that employees in "just" organizations tend to be duty-orientated by upholding the vision and mission of the organization, helping their colleagues and respecting the values and beliefs of the companies for purposes of enhancing business prosperity (Hannah *et al.*, 2014). The findings are supported by previous studies (Akram *et al.*, 2020; Imamoglu *et al.*, 2019), which investigated the link between organizational justice and discretionary behaviours. For example, the evidence documented in the Akram *et al.* (2020) study points to the conclusion that organizational justice spurs innovative work behaviours among employees in the telecommunications sector.

Further, our study revealed that SPR have a significant positive association with duty orientation in the mining sector of Ghana. This means that supervisor-provided resources tend to attract employees to appreciate the firms they work for with a duty orientation. This finding has found expression in the social exchange and organizational justice theories in which Stafford and Kuiper (2021) argue that employees' value beneficial interactions with supervisors and will, in the spirit of reciprocity, engage in useful acts such as duty orientation. Also, because supervisors are at the forefront of organizations and control resources, initiatives they take in the form of providing the right resources incite employees to demonstrate duty orientations (Lemmon *et al.*, 2016; Hannah *et al.*, 2014). Particularly, employees cherish affection and good relationships as well as the provision of sufficient information towards the execution of their roles (Rabbani *et al.*, 2017).

Finally, the findings revealed that supervisor-provided resources partially mediate the link between organizational justice and duty orientation. The implication is that although organizational justice can influence the duty orientation of employees in the company, such influence can be improved when the employees perceive the adequate presence of SPR. Within the tenets of reciprocity (Blau, 1964), employees will demonstrate improved behaviours of duty orientation when organizational justice and SPR are complimentarily effective in mining companies. Generally, employees who perceive fairness in their organization tend to perceive their jobs as satisfying and meaningful and thus become more responsive to the goals of the organization, the codes of the teams and the overall mission of the organization (Ansong *et al.*, 2022; Akram *et al.*, 2016).

Theoretical implications

The findings of the study are prominent in many ways. Based on our review of the extant literature, previous studies have primarily analysed how organizational justice predicts employees' behaviours such as work innovative behaviour (Akram *et al.*, 2020),

organizational citizenship behaviours (Yuen Onn *et al.*, 2018), employee commitment and psychological resilience (Quratulain *et al.*, 2012). This study, thus, contributes to the literature by adding duty orientation to the list. Besides providing clarity on some of the determinants of duty orientation among employees, the results answered the call by some scholars (Aggarwal *et al.*, 2022; Akram *et al.*, 2020; Jehanzeb and Mohanty, 2020) for the need to broaden the nature of investigations on the effects of organizational justice on employee behaviour through a broader contextual study that will include plausible intervening variables. The findings provide crucial pointers to organizations on the role of SPR in fostering the relationship between organizational justice and positive employee behaviour-related constructs. Moreover, the evidence documented in the Ghanaian context on the role of organizational justice and SPR forms a fundamental reference for future scholars in related fields. The study has broadened the scope of knowledge on the factors organizations can leverage to promote duty orientation among employees.

The findings further shed light on the organizational justice and social exchange theories by establishing that employees feel the obligation to give back valuable efforts in response to essential services and practices offered to them by the organization. In sum, organizational justice elevates workers' extra work roles by promoting employees' duty orientation (Ansong *et al.*, 2022). The findings strengthen the arguments of organizational justice, organizational support and social exchange theories, given that employees perceive justice as an important resource and support that has the potential to provoke positive work behaviours.

Practical implications

The evidence gathered from the study is useful for managers of mining companies and policymakers in the production sector of the Ghanaian economy. Within the contemporary business environment, good organizational policies and systems have been the centre of business success, and firms should not ignore the role of organizational justice in stimulating the duty orientation of employees. Although duty orientation is a sort of discretionary employee attitude, essential company policies like organizational justice and supervisor-provided resources are critical success factors for its enforcement in the organization. In light of these, the management of the mining companies should devote resources to developing organizational justice policies based on fairness in resource allocation, clear roles, employee feedback and effective information dissemination. Management of the companies could also strategically outline and incorporate good pay policies, promotion, performance appraisals and quality of work–life in running their affairs. Moreover, the management of mining companies can ignite the duty orientation of their employees by showing love and affection, recognizing them, providing them with complete information and demonstrating confidence in their abilities. Again, supervisors or managers at the operational level should have a clear perspective on how to conceptualize and administer social, task and financial resources. It would be prudent for supervisors to place priority on acquiring and dispensing these resources in a fair manner. This can be achieved if organizations correlate resource flows and incentives with employee outcomes. These practices would encourage employees to reciprocate good behaviour towards their organization by being duty-orientated.

Conclusions

Following the findings that emerged, the study concludes that organizational justice and SPR are critical factors for spurring duty orientation in mining firms in Ghana. This suggests that the firms should empower the various supervisors to exercise organizational justice in the allocation and delivery of resources to subordinates to demonstrate duty orientation. Considering the high demands from employees to show innovative and loyal behaviours on

the job, it is essential for management to adore policies that would foster these behaviours among the employees. Since duty orientation captures the volition to pursue the overall interests of firms, the study would broadly recommend that practitioners and policymakers to pay attention to behavioural measures that promote favourable employee outcomes.

Limitations and suggestion for future studies

Although the study presented essential findings on how management and policymakers in the mining sector will integrate organizational justice policies with supervisor-provided resources to enhance duty orientation, it should be treated as preliminary until further studies replicate the study in other broad settings. We recommend that future studies consider longitudinal and experimental research to help confirm the causal paths investigated in the present study. Again, the study relied on self-reported measures in the data collection procedure. Despite the fact that some researchers claim self-reported bias is trivial and rarely invalidates research findings, it is possible that the findings of the present study may be contaminated by the same source bias. It is recommended that future studies consider a mixed approach and relevant control and moderating variables like gender to better understand the phenomenon studied.

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Appendix

The supplementary material for this article can be found online.

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Sustainability performance in science and technology parks: how can firms benefit most?

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Abstract

Purpose – Achieving good sustainability performance requires balancing higher economic profits with better environmental and social performance. Knowledge plays a key role in improving corporate sustainability performance, but this knowledge is becoming increasingly complex, specific and dispersed among many scientific, technological and business actors. Science and technology parks (STPs) are infrastructures designed to host varying types of organizations that can bring together new, disruptive knowledge. Our purpose is to unveil how these spaces can be drivers of sustainability performance for companies.

Design/methodology/approach – We test our hypotheses on a longitudinal database of Spanish companies over the period 2009–2016 using structural equation models (SEMs).

Findings – This research confirms that a firm's location in an STP helps improve its sustainability performance, provided that conditions are optimal in the STP. These optimal conditions are based on an abundance of knowledge spillovers available to the firm and the firm's ability to harness them, especially those of a more disruptive nature, through absorptive capacity.

Originality/value – Results of this study yield implications for academia in the form of future lines of research and practical implications for policymakers and managers of both STPs and the organizations that host them.

Keywords Sustainability performance, Science and technology parks, Knowledge spillovers, Absorptive capacity, Panel dataset, Structural equation modeling

Paper type Research paper

1. Introduction

The concept of sustainability has dominated the agendas of governmental and non-governmental entities, academic institutions and, more recently, the business sector (Feliciano *et al.*, 2022; Leal-Filho *et al.*, 2021). In the business world, internal and external factors are prompting more companies to voluntarily adopt broader roles and responsibilities, implementing a holistic management approach to balance economic, social and environmental performance for the benefit of current and future generations (Aragón-Correa *et al.*, 2020; Ozbekler and Ozturkoglu, 2020).

Corporate performance and long-term competitiveness increasingly depend on the ability to balance economic, environmental and social expectations (Forés, 2019; De Marchi and Grandinetti, 2013; Hart and Dowell, 2011). There is a general consensus that science and technology (ultimately, knowledge) will play a key role in firms' ability to improve

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competitiveness in terms of sustainability performance and achieve sustainability goals such as the Sustainable Development Goals (SDGs) (e.g. Walsh *et al.*, 2020; Forés, 2019).

Knowledge is becoming increasingly complex and specific, and it is distributed among a wide range of economic agents (Scuotto *et al.*, 2017; Chesbrough, 2003). Accessing external knowledge sources facilitates the development of ecological or social innovations (Kennedy *et al.*, 2017; Laursen and Salter, 2006). To radically innovate, a firm may require information beyond what it can find within its own boundaries; that is, it will need to harness inter-organizational knowledge flows (e.g. Ferraris *et al.*, 2017; Wang *et al.*, 2017).

Science and technology parks (STPs) are infrastructures designed to host very different types of organizations, such as established companies, start-ups, research institutes and spin-offs of university research groups or technological institutes (Díez-Vial and Montoro-Sánchez, 2016; Guadix *et al.*, 2016). In STPs, physical proximity, complementarity and shared services can stimulate interaction between organizations and generate new knowledge (Albahari *et al.*, 2023; Díez-Vial and Montoro-Sánchez, 2016).

Thus, integration in a territorial agglomeration of companies (such as an STP) may be an antecedent of improved corporate sustainability performance (González-Masip *et al.*, 2019), aided by the knowledge spillovers that emerge in these spaces. Although previous research has analyzed how the location of a company in an STP impacts measures of economic and/or innovative performance (e.g. Ubeda *et al.*, 2019), there are still very few studies that explore this company performance measured not only in economic, but also in social and environmental terms. Our proposal therefore aims to contribute to fill this gap in the literature.

Moreover, in this study, we account for the idea that the benefits of being located in an STP do not depend exclusively on the firm having access to more knowledge spillovers, but also on its internal strategies to make effective use of these localized endowments of knowledge (Camisón *et al.*, 2018; Claver-Cortés *et al.*, 2018; Camisón and Forés, 2011). A firm can only take advantage of knowledge spillovers to improve its sustainability performance if it can identify and integrate them into its current knowledge base and later apply them for that purpose (Marrucci *et al.*, 2022; Claver-Cortés *et al.*, 2018; De Marchi, 2012).

In addition, depending on the degree of similarity between knowledge spillovers from the environment and the company's current cognitive bases, some can be easily integrated and combined with the company's knowledge endowments (Camisón *et al.*, 2018; March, 1991). In contrast, other, more tacit, complex, knowledge spillovers at the knowledge frontier require the firm to develop an absorptive capacity capable of multiplying the effect of these localized knowledge endowments on its sustainability performance (Camisón *et al.*, 2018; Camisón and Forés, 2011). There are also few empirical contributions on the direct and indirect effects of absorptive capacity on sustainability performance (e.g. Claver-Cortés *et al.*, 2018).

Consequently, the aim of this research is to advance the literature by providing empirical evidence of the effects of STP location on the sustainability performance of Spanish firms, through the mediating effects of knowledge spillovers and individual firms' absorptive capacity. Specifically, our study aims to provide answers to the following research questions:

RQ1. To what extent can knowledge spillovers and absorptive capacity be considered antecedent factors of sustainability?

RQ2. Does the firms' location in innovation spaces, such as STPs, matter for sustainability performance?

RQ3. What is the effect of STP on the pooling and deployment of knowledge spillovers and the firm's absorptive capacity?

To respond to these questions, we conduct a longitudinal empirical analysis of data extracted from the Panel on Technological Innovation in Spanish Companies (PITEC). The rest of the paper is structured as follows: the next section presents the conceptual framework and

hypotheses; then, we describe the methodology and detail the results; finally, the last section presents the conclusions, future lines of research and recommendations for managers to contribute more actively to achieving a more sustainable society.

2. Conceptual framework

Sustainability represents a paradigm shift in today's competitive landscape and poses a major challenge to firms' competitive advantage (Shahzad *et al.*, 2020). Thus, competitive success increasingly depends on firms being able to reconcile economic performance with a reduction in the impact of their activity on the environment, while improving the society in which they operate. Achieving a balance between all these determinants of business success is not straightforward and requires companies to increase their knowledge base on new technologies, business practices, legal regulations and stakeholder expectations, in order to improve their triple bottom line performance (e.g. Walsh *et al.*, 2020; Abbas and Sagsan, 2019).

In today's competitive arena, many studies underline the importance of external knowledge in complementing a company's internal knowledge to meet new business challenges, as a single company may not have all the necessary knowledge on such a complex issue as sustainability within its own boundaries (Hernández-Trasobares and Murillo-Luna, 2020; Roper *et al.*, 2017; Chesbrough, 2003). Knowledge spillovers, understood as the process in which knowledge is transferred from the producer or source of that knowledge to the recipients or users of knowledge (Wang *et al.*, 2017), represent one of the main forms of external knowledge that the firm can access. Implicit in the conception of knowledge spillovers is the effort that the company should make to be an active part of the community of agents, processes and networks in which these knowledge flows are generated (Bellandi and De Propis, 2015; Granovetter, 1985).

These knowledge spillovers that can help firms to improve their performance come from different sources (Hernández-Trasobares and Murillo-Luna, 2020; García-Martínez *et al.*, 2017; Rodríguez *et al.*, 2017), such as suppliers, customers, or competitors (Rodríguez *et al.*, 2017; De Marchi, 2012). Other sources of knowledge spillovers include education and research entities such as universities, research or technology centers and consultants (Rodriguez *et al.*, 2017). Finally, relevant knowledge spillovers can be easily produced and distributed in conferences and trade fairs or scientific journals and trade publications (Rodriguez *et al.*, 2017; Laursen and Salter, 2006).

If they are similar to the firm's existing knowledge and experiences, some of these knowledge spillovers can enhance efficiency or provide new solutions to develop skills, products, or processes, stimulating the creation of synergies between both sets of knowledge without requiring dynamic learning capabilities (Camisón *et al.*, 2018; March, 1991). In light of the above, we propose that:

H1. Knowledge spillovers have a positive effect on sustainability performance

However, not all external knowledge is related to the company's existing knowledge background and cognitive models (Camisón *et al.*, 2018). In these situations, knowledge spillovers tend to be tacit, complex and innovative in nature, meaning firms' absorptive capacity (Zahra and George, 2002; Cohen and Levinthal, 1990) becomes crucial.

According to Albort-Morant *et al.* (2018), absorptive capacity allows firms to have cutting-edge knowledge of technologies and innovations that promote more sustainable products and processes. Similar results are found by Abbas and Sagsan (2019) for a sample of 302 Pakistani manufacturing and service firms, confirming that absorptive capacity influences the adoption of more sustainable technologies and management practices, impacting the triple bottom line.

Contrary to the previous hypothesis, absorptive capacity always implies exploring and integrating new combinations of internal and external knowledge, requiring greater learning

efforts on the part of the firm (Camisón *et al.*, 2018; March, 1991; Cohen and Levinthal, 1990). Therefore, absorptive capacity, as a dynamic capacity (Hussain *et al.*, 2022; Claver-Cortés *et al.*, 2020; Forés and Camisón, 2016), leads to disruptive changes in the company's stock of knowledge, technological assets and functional capabilities that have a direct impact on the development of new products, the redeployment of production processes, market positioning and compliance with legal requirements in the field of sustainability (Shahzad *et al.*, 2020; Abbas and Sagsan, 2019). Thus:

H2. Absorptive capacity has a positive effect on sustainability performance

2.1 The mediating effect of absorptive capacity

However, in this competitive arena with frequent, sophisticated changes in technologies and markets, firms cannot rely solely on their internal knowledge creation capabilities or the adoption of new incremental knowledge aimed at more efficiently exploiting the firm's existing capabilities (Guisado-González *et al.*, 2021; Forés and Camisón, 2016). To develops resources and capabilities that can have a truly disruptive impact on firm performance, exposure to a wide range of novel sources of knowledge is not enough; the knowledge needs to be properly identified, evaluated, assimilated and institutionalized to be able to apply it to the firm's purposes (Hussain *et al.*, 2022; Song *et al.*, 2018; García-Martínez *et al.*, 2017; Forés and Camisón, 2016). This process is not free of costs, as harnessing these knowledge spillovers requires the firm to first generate a critical mass of knowledge internally that allows it to apply this radical new knowledge (Song *et al.*, 2018; Cohen and Levinthal, 1990).

We consider that absorptive capacity ensures the acquisition, assimilation, transformation and exploitation of different knowledge spillovers, enabling the generation of new functional capabilities (e.g. production, marketing, etc.) that help improve firms' sustainability performance to meet the demands of their environment and stakeholders (Hussain *et al.*, 2022; Dzhengiz and Niesten, 2020; Forés and Camisón, 2016). A company with adequate absorptive capacity will be able to multiply the impacts of the knowledge spillovers from its environment, which will ultimately have a significant effect on enhancing sustainability performance. Therefore:

H3. Absorptive capacity mediates the relationship between knowledge spillovers and sustainability performance

2.2 Direct effects of integration in a science and technology park on knowledge spillovers

Since the pioneering work of Alfred Marshall (1890), there has been a consensus in the academic literature that the creation of knowledge applicable to new innovations and capable of boosting firm competitiveness is more successful when it is geographically bounded (e.g. Ascani *et al.*, 2020; Arranz *et al.*, 2019; Hervás-Oliver *et al.*, 2018). Indeed, STPs are a policy tool aimed at fostering the creation of knowledge and organizational learning processes in a specific environment by stimulating the links between industry and academia, encouraging the creation of new knowledge-based companies, as well as providing on-park companies with other benefits such as improved image and prestige, or easy access to customers, technological research centers and a highly trained workforce (González-Masip *et al.*, 2019; Gwebu *et al.*, 2019; Arauzo-Carod *et al.*, 2018).

Notwithstanding, the endowment of this bundle of market resources derived from the location alone cannot fully explain why some STPs are able to help on-park companies to improve their performance. Therefore, this co-location of organizations may serve as a trigger for enhancing localized knowledge spillovers through the relationships developed between companies, R&D institutions, experts and consultants and local institutions (Albahari *et al.*, 2023; Camisón and Forés, 2011).

Moreover, in order for organizations to correctly identify these knowledge spillovers, they must have a sense of embeddedness in or belonging to the processes, networks and institutions in the STP (Hervás-Oliver *et al.*, 2018; Camisón and Forés, 2011). Therefore, a firm that is located inside an STP but keeps its distance from other co-localized agents will be deprived of access to these knowledge spillovers, or even incapable of correctly identifying them. Therefore:

H4. The organization belonging to a STP has a positive effect on knowledge spillovers

2.3 The mediating effects of knowledge spillovers and absorptive capacity on sustainability performance

Although the literature notes the advantages of an organization being located in an STP, due to a lack of empirical studies, there is no clear consensus as to whether this location is a driver of business success, especially concerning sustainability performance. Thus, while certain empirical studies confirm the beneficial effect of STP location on economic or innovative performance (e.g. Arauzo-Carod *et al.*, 2018; Albahari *et al.*, 2017; Díez-Vial and Fernández-Olmos, 2017), other research reports opposite results or, at best, declares a non-significant effect of the STP (e.g. Lamperti *et al.*, 2017; Liberati *et al.*, 2016; Hansson *et al.*, 2005) and rules it out as a determinant of business success.

Several empirical studies relying on the resource-based view (e.g. Ubeda *et al.*, 2019; Zahra and George, 2002) argue that the aforementioned disparity in the findings about the effect of on-park location lies in the internal dynamics of the firm and how it can take advantage of the benefits and opportunities offered by these STPs (e.g. Ubeda *et al.*, 2019; Claver-Cortés *et al.*, 2018; Hervás-Oliver *et al.*, 2018; Díez-Vial and Montoro-Sánchez, 2016). It can thus be concluded that a company located in an STP that aims to improve its performance, especially if this performance is measured from the triple bottom line of sustainability, must make conscious efforts to take advantage of the knowledge and resources provided by this environment.

As stated in the seminal article by Cohen and Levinthal (1990), the wealth of complex knowledge spillovers that flourish from a firm's embeddedness in an STP can exert a push effect on co-located organizations to increase their absorptive capacity (Song *et al.*, 2018). Thus, access to plentiful knowledge spillovers should encourage firms to increase their absorptive capacity, to better exploit co-located agents' knowledge and thus possess cutting-edge knowledge (Camisón and Forés, 2011).

In light of the above, we propose the fifth hypothesis:

H5. Knowledge spillovers mediate

(a) the relationship between the organization belonging to a STP and sustainability performance

(b) the relationship between the organization belonging to a science and technology and absorptive capacity

Considering that innovation can be a driver of improved environmental (e.g. Parrilli *et al.*, 2023; Shahzad *et al.*, 2020) and social (e.g. Cillo *et al.*, 2019) performance and that absorbed knowledge has been found to enhance economic, environmental and social performance (e.g. Walsh *et al.*, 2020; Albort-Morant *et al.*, 2018; De Marchi and Grandinetti, 2013), we examine the role of absorptive capacity in mediating the relationship between a firm's location in an STP and its triple bottom line performance. From this perspective, absorptive capacity amplifies the sustainability benefits of on-park location in terms of knowledge generation and sharing. An empirical study by Claver Cortés *et al.* (2018) confirms the mediating effect of absorptive capacity on the relationship between STP location and improved innovative

performance. Therefore, also considering the arguments raised in H3 and H5b, we pose the following final hypothesis:

H6. The impact of belonging to a STP on sustainability performance is mediated by the influence of knowledge spillovers on absorptive capacity

Figure 1 below presents the model as a whole as well as all the hypothesized relationships between the variables.

3. Methodology and results

3.1 Data and sample

We use data from the Technological Innovation Panel (PITEC) for Spanish companies. The PITEC is based on the Community Innovation Survey (CIS) database used to analyze European Union (EU) firms' innovation activities and results (Estrada and Zhou, 2022).

PITEC, which has a panel structure, contains organization-level data and provides basic company descriptors as well as detailed information on employment, sales and exportation activity. However, most of the information in this database is related to innovation activity.

The reference period for the research is 2009–2016, due to a lack of previous data on some of the study variables (e.g. sustainability performance). In our analysis, we use an unbalanced panel of 8,874 companies which have conducted some sort of sustainability initiatives in the seven-year period, yielding a total sample of 47,870 observations.

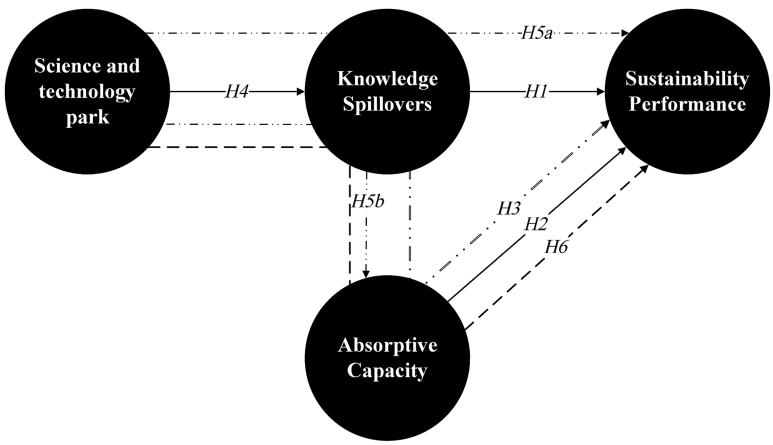
Figure 2 presents the evolution of on- and off-park companies in PITEC from 2009 to 2016, considering not only movements to and from the STP, but also businesses that disappear or come into existence during this period.

As explained in the following section, we have used the number of years located in the park as an alternative measure for the independent variable belonging to an STP, as it is an important determinant of the firm's capacity to benefit from on-park location (Albahari *et al.*, 2023).

3.2 Measures

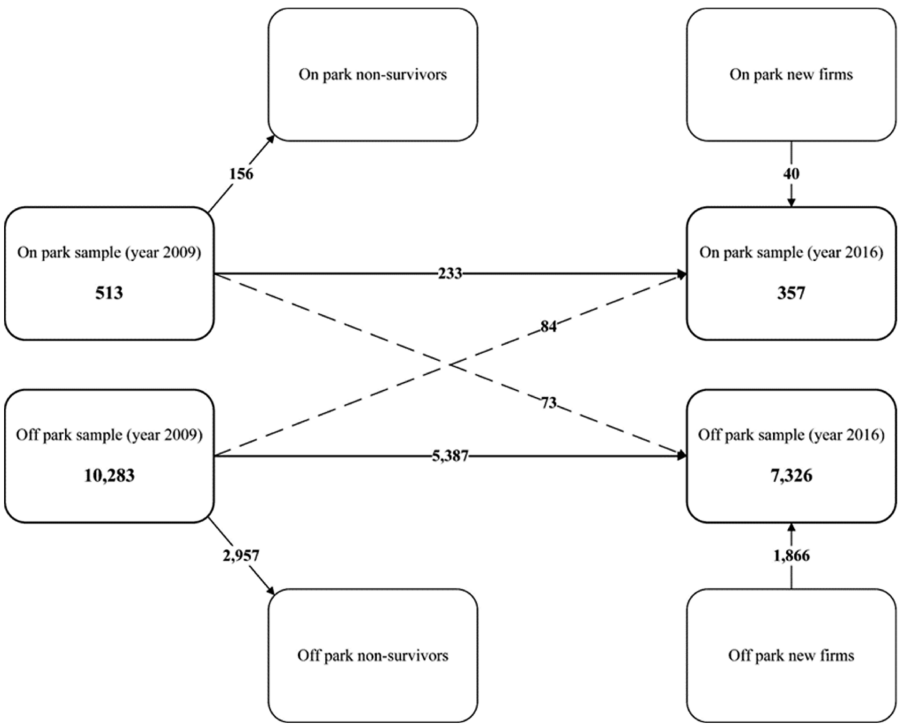
Table 1 presents a precise description of how the study's variables were constructed.

Table 2 presents the summary statistics and Table 3 the correlations among the study variables and variance inflation factor (VIF) coefficients. Correlation values among all



Source(s): Authors' own elaboration

Figure 1.
Research model



Source(s): Authors' own elaboration

Figure 2.
Evolution of the organizations in the panel dataset

variables are generally low to moderate (Table 3), indicating a low risk of collinearity issues or redundancies with this set of variables. The highest correlations shown in italics are for alternative measures of the dependent (SUSTAIN) and independent variables (STP and SPILL), introduced in the robustness analysis section. However, these correlations should not be considered in the main analysis. Taking this into account, the highest correlation is 0.578, below what is considered problematic. The rule of thumb is that correlation values should not exceed 0.75, or the stricter limit of 0.6 (Churchill, 1979).

This is confirmed by the analysis of the variance inflation factor. The maximum variance inflation factor value is 1.22, well below the rule-of-thumb cut-off of 10, which again indicates that there are no serious multicollinearity problems in the models (Hair *et al.*, 2006).

In addition, we performed a number of statistical analyses to assess the severity of common method bias. First, the Harman's one-factor test indicated that common method bias was not an issue: multiple factors were detected, and the variance did not stem only from the first factors (Podsakoff *et al.*, 2003). In fact, the independent variables included in the model form several factors with eigenvalues higher than 1 and the first two factors capture only 22.25 and 15.8% of the total variance, respectively. We also included control variables that have a bivariate correlation with the other variables in the model of below 0.4 (Siemsen *et al.*, 2010).

3.3 Model estimation and results

We analyzed the main relationships of our model using SEM techniques, as they are very useful for analyzing mediation hypotheses (James *et al.*, 2006). The main hypotheses of our

Measure	Definition	Variable	Scale
Dependent variable: Sustainability performance Cronbach's Alpha = 0.91	This construct was formulated to include the three dimensions considered in the literature (e.g. Shang *et al.*, 2020): environmental, economic and social sustainability	Following previous antecedents in the literature (e.g. Acebo *et al.*, 2021; González-Blanco *et al.*, 2018), we calculate this construct as the sum of the scores about the importance of the following 16 organizational sustainability objectives (i) Increase in the offered number of products or services; (ii) Old product substitution; (iii) New market penetration; (iv) Increase in market share; (v) Increase in quality; (vi) Increase in product flexibility; (vii) Increase in production capacity; (viii) Labor cost reduction (per unit produced); (ix) Material cost reduction (per unit); (x) Energy cost reduction (per unit); (xi) Reduction in environmental impact; (xii) Compliance with environmental, health and safety regulation; (xiii) Increase in total employment; (xiv) Increase in qualified employment; (xv) Maintenance of employment; and, (xvi) Increase in employees' health and safety. These questions were answered on a four-point scale of importance (ranging from between 0 for "not used" and 3 for "high importance"), but, before summing the items, we coded these questions as binary variables (1 if the company indicates either "medium" or "high" importance, 0 otherwise)	0–16
Independent variables			
Belonging to a science and technology park (STP)	This variable distinguishes companies that are located in science and technology parks from those that are not (e.g. Diez-Vial and Fernández-Olmos, 2017)	Following previous studies in the literature (e.g. Diez-Vial and Fernández-Olmos, 2017; Yang *et al.*, 2009), this dichotomous variable takes the value of 1 when an organization is located in a science and technology park and 0 otherwise	0–1

(*continued*)

Table 1.
Study's variables

Measure	Definition	Variable	Scale
Knowledge spillovers Cronbach's Alpha = 0.82	Knowledge spillovers are any original, valuable knowledge which becomes publicly accessible (Cohen and Levinthal, 1989)	Following previous studies (e.g. González-Blanco *et al.*, 2018; Rodríguez *et al.*, 2017), the aggregate construct is the sum of the scores about the importance of the following 11 information sources for the innovation process: (i) Sources within the organization's enterprise group; (ii) Suppliers; (iii) Clients; (iv) Competitors; (v) Consultants and commercial labs; (vi) Universities or other higher education institutions; (vii) Public research institutes; (viii) Technological institutes; (ix) Conferences; (x) Scientific journals and technical publications; and, (xi) Professional and industry associations Each source was measured with an item capturing the degree of importance (ranging between 0 for "not used" and 3 for "high"). We rescaled each item before aggregating them, assigning a value for 0 (not used and low importance), or 1 (medium and high importance). Thus, with 10 items in total, the final external knowledge sources measure ranges from 0 to 11	0–11
Absorptive capacity (ACAP) Cronbach's Alpha = 0.6	The ACAP is the firm's ability to "recognize the value of new, external information, assimilate it and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128)	As proposed in previous studies (e.g. Diez-Vial and Fernández-Olmos, 2017), we sum the scores obtained in the following five binary variables aimed at capturing whether the respondent's company has carried out any of the following activities: (i) Internal research and development; (ii) External research and development; (iii) Acquisition of machinery and equipment; (iv) Acquisition of external knowledge; and, (v) Internal and external training for innovation activities	0–5
Control variables (Albahari *et al.*, 2023; Arranz *et al.*, 2019; De Marchi, 2012)			
Size (SIZE)	–	To capture the effect of the company's size on sustainability performance, we introduced the number of employees	Continuous

Table 1. (*continued*)

Measure	Definition	Variable	Scale
Exports (EXPORTS)	–	We control of the firm's international scope (Arranz *et al.*, 2019) based on a question asking about the percentage of company turnover generated in foreign markets	Continuous
Industry (INDUSTRY)	–	We introduce a dummy variable that takes the value 1 if the business belongs to the manufacturing industry and 0 if it belongs to the service industry	0–1

Source(s): Authors' own elaboration

Table 1.

Variable	Obs	Mean	Std. Dev	Min	Max
SUSTAIN	47,870	8.502	4.998	0	16
ECOSUSTAIN	47,870	5.139	2.621	0	8
ENVIROSUSTAIN	47,870	1.57	1.46	0	4
SOCIALSUSTAIN	47,870	1.793	1.629	0	4
STP	71,571	1.049	0.216	1	2
STPMAT	102,678	0.222	1.242	0	8
SPILL	47,870	4.502	3.041	0	11
MARKSPILL	47,870	2.733	1.551	0	5
SCIENSPILL	47,870	1.77	1.928	0	6
ACAP	71,571	0.87	1.049	0	5
SIZE	71,571	337.806	1617.855	1	40,924
EXPORTS	71,571	1066.852	283195.61	0	75,762,636
INDUSTRY	71,571	0.512	0.5	0	1

Source(s): Authors' own elaboration

Table 2.
Descriptive statistics

model are confirmed (Table 4 and Figure 3), with consistent results for the main independent variables. The results also show that all the control variables considered (SIZE, EXPORTS and INDUSTRY) have a positive significant effect on sustainability performance.

Additionally, tests were performed to verify the consistency, goodness of fit and predictive relevance of the model. With respect to model consistency—the R2 value of the dependent variable—the model explains 37.40% (Figure 3) of the total variance in sustainability performance. The comparative fit index (CFI) and Tucker–Lewis index (TLI) fit statistics are close to 1, and the root mean square error of approximation (RMSEA) value is below 0.05 with a probability also near to 1 (Bentler, 1990), showing the good fit and predictive power of the model (see Appendix, part 1).

The mediating effects established in the model (hypotheses 3, 5 and 6) are all confirmed using additional Monte Carlo tests using STATA software (see Appendix, part 2).

3.4 Robustness analysis

To confirm the consistency of the results presented in the last section, we performed a series of robustness checks for the independent and dependent variables of our conceptual model.

In the case of the independent variables, we have estimated the SEM model using an alternative measure of the dichotomous variable STP, which indicates the number of years

Table 3.
Correlation and VIF coefficients

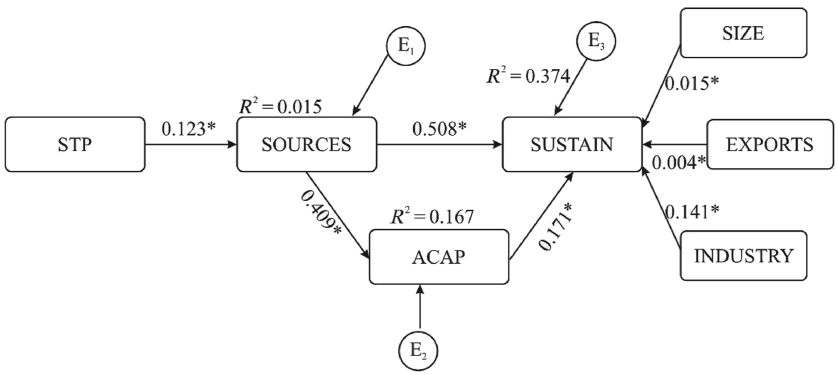
Variables	(1)	(1a)	(1b)	(1c)	(2)	(2a)	(3)	(3a)	(3b)	(4)	(5)	(6)	(7)	VIF = 1.09
(1) SUSTAIN	1.000													
(1a) ECOSUSTAIN	0.902*	1.000												
	(0.000)													
(1b) ENVIROSUSTAIN	0.862*	0.636*	1.000											
	(0.000)	(0.000)												
(1c) SOCIALSUSTAIN	0.845*	0.587*	0.724*	1.000										
	(0.000)	(0.000)	(0.000)											
(2) STP	0.041*	0.040*	0.029*	0.035*	1.000									1.05
	(0.000)	(0.000)	(0.000)	(0.000)										
(2a) STPMAT	0.045*	0.042*	0.033*	0.040*	0.953*	1.000								
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)									
(3) SPILL	0.578*	0.533*	0.468*	0.495*	0.123*	0.125*	1.000							1.21
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)								
(3a) MARKSPILL	0.581*	0.582*	0.443*	0.448*	0.073*	0.076*	0.841*	1.000						
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)							
(3b) SCIENSPILL	0.444*	0.373*	0.382*	0.419*	0.136*	0.135*	0.901*	0.523*	1.000					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)						
(4) ACAP	0.386*	0.377*	0.293*	0.316*	0.136*	0.139*	0.409*	0.374*	0.344*	1.000				1.22
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
(5) SIZE	0.027*	0.022*	0.013*	0.034*	−0.018*	−0.017*	0.035*	0.045*	0.019*	0.057*	1.000			1.02
	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
(6) EXPORTS	0.007	0.005	0.008	0.006	−0.001	−0.001	0.008	0.004	0.010*	−0.003	0.000	1.000		1
	(0.133)	(0.275)	(0.096)	(0.175)	(0.821)	(0.829)	(0.070)	(0.413)	(0.028)	(0.409)	(0.899)			
(7) INDUSTRY	0.158*	0.111*	0.158*	0.163*	−0.107*	−0.100*	0.016*	0.063*	−0.025*	0.150*	−0.112*	−0.004	1.000	1.05
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.307)		

Note(s): *Shows significance at $p < 0.05$
Source(s): Authors' own elaboration

Standardized	Coefficient	std. err	z	Robust $p > z$	[95% conf	Interval]
Structural						
SPILL						
SPT	0.123	0.005	26.210	0.000	0.114	0.133
_cons	0.946	0.021	44.660	0.000	0.904	0.987
SUSTAIN						
SPILL	0.508	0.004	132.540	0.000	0.500	0.515
ACAP	0.171	0.004	44.110	0.000	0.163	0.178
SIZE	0.015	0.003	4.530	0.000	0.008	0.021
EXPORTS	0.004	0.000	77.730	0.000	0.004	0.005
INDUSTRY	0.141	0.004	38.830	0.000	0.134	0.148
_cons	0.576	0.008	70.600	0.000	0.560	0.592
ACAP						
SPILL	0.409	0.004	107.37	0.000	0.401	0.416
_cons	0.643	0.007	86.97	0.000	0.629	0.658
var(e.SPILL)	0.985	0.001			0.983	0.987
var(e.SUSTAIN)	0.626	0.004			0.619	0.633
var(e.ACAP)	0.833	0.003			0.827	0.839

Note(s): Structural equation model, Number of obs = 47,870
Estimation method: ml
Log pseudolikelihood = −1457329.3
Source(s): Authors' own elaboration

Table 4.
SEM model estimation results



Source(s): Authors' own elaboration

Figure 3.
SEM model estimation results

the firm has been in an STP, or its STP maturity (STPMAT) [1]. We believe this variable may better capture the firm's structural characteristics linked to its experience in the park that explain both the firm's embeddedness in the knowledge spillovers and its capacity to harness them for innovation (Albahari *et al.*, 2023; Camisón and Forés, 2011). The results obtained (Appendix, part 3) are similar to those of the original model (Figure 3).

We also run the model distinguishing market spillovers (MARKSPILL) (enterprise group; suppliers, clients; competitors; consultants and commercial labs) from scientific and professional spillovers (SCIENSPILL) (universities or other higher education institutions; public research institutes; technological institutes; conferences, trade fairs and exhibitions;

scientific journals and technical publications; and professional and industry associations) (Diez-Martinez *et al.*, 2022; Del Río *et al.*, 2017). We also obtain consistent results for the main independent variables (Appendix, part 4), confirming the validity and robustness of the relationships in our conceptual model.

To confirm the mediating effects in the model, we also carry out a hierarchical regression analysis using panel data. To control for endogeneity and autocorrelation bias, we estimate the model using fixed-effects with robust standard errors (Acebo *et al.*, 2021), based on the results from the Hausman specification test. Following the methodology proposed by Baron and Kenny (1986), the results (Appendix, part 3) show that there is a significant relationship between STP and SUSTAIN (Model 1), between STP and SPILL (Model 2) and STP and ACAP (Model 3). However, when considering the effect of the independent variables, STP and SPILL, on ACAP (Model 4) and of STP, SPILL and ACAP on SUSTAIN (Model 4), the direct effect of STP on both ACAP and SUSTAIN disappears. These results confirm that SPILL fully mediates both the relationship between the organization belonging to an STP and SUSTAIN (H5a) and the relationship between the organization belonging to an STP and ACAP (H5b). The results from the regression analysis in Model 1 also indicate that only EXPORTS has a positive significant effect on sustainability performance.

Finally, based on the previous multiple regression analysis, we cross-checked our results using alternative measures for our dependent variable sustainability performance based on the triple bottom line conceptualization of the construct (Ben Arfi *et al.*, 2018). Specifically, we consider each dimension that makes up the sustainability performance construct: economic (comprising items related to market product and process technology), environmental (items related to green technology and compliance with standards) and social (items related to employment and employees' qualifications and welfare). We thus ran three additional model specifications: Model 6 for economic performance (ECOSUSTAIN), Model 7 for environmental performance (ENVIRONSUSTAIN) and Model 8 for social performance (SOCIALSUSTAIN) (see Appendix, part 5). Comparing the estimates with those from the baseline model, we can confirm the main results of the baseline model hold with only very minor changes. The direction of the effects of the explanatory variables remains the same across the models (Appendix, part 5).

4. Discussion, conclusions and future lines of research

Academic research and international frameworks such as the 2030 Agenda show that organizations can no longer conduct business as usual; they must make greater efforts to ensure a more sustainable world (Hernández-Trasobares and Murillo-Luna, 2020; Walsh *et al.*, 2020; Forés, 2019). To do so, companies will need to broaden their knowledge bases and develop through learning processes.

As confirmed in H1 ($\beta = 0.508$, $p < 0.001$; Table 4), a greater diversity of knowledge spillovers positively impacts triple bottom line sustainability performance. The capacity of the firm to accumulate new knowledge, encapsulated in the absorptive capacity construct, is also shown to be an important determinant of sustainability performance, confirming H2 ($\beta = 0.171$, $p < 0.001$; Table 4). This result provides support to previous literature on the importance of dynamic capabilities for the generation of new products, processes and organizational forms that have an impact on the market, the environment and the society.

In addition, findings show that certain radical new knowledge spillovers, relative to the firm's previous knowledge stock, require a prior absorption process to have an impact on improving sustainability performance. This study thus shows the role of absorptive capacity as a catalyst of knowledge spillovers' effect on sustainability results, supporting H3 ($\beta = 0.07$, $p < 0.001$; Table 4).

STPs have been categorized as learning centers, in which there is a confluence of scientific, technological and business actors (Link and Scott, 2018). However, as the literature on knowledge management and innovation has underlined, merely being located in a space rich in knowledge spillovers does not necessarily mean a firm can correctly identify, assimilate and exploit new external knowledge (e.g. Ubeda *et al.*, 2019; Claver-Cortés *et al.*, 2018; Camisón and Forés, 2011). Our analysis of Spanish firms using the PITEC panel database allows us to confirm previous research findings about the successive influence of knowledge flows and then absorptive capacity on the relationship between STP location and better sustainability performance.

The effects of on-park location are not the same for these two antecedents of sustainability performance: while it has a direct impact on the knowledge spillovers that the firm can identify and exploit, absorptive capacity does not. Our empirical study shows that on-park location impacts the generation of spillovers and their degree of diversity as measured by the number of agents involved, confirming hypothesis 4 ($\beta = 0.123$ $p < 0.001$; Table 4). It also confirms the fully-mediating role that knowledge spillovers play in the relationship between the organization belonging to an STP and sustainability performance, as posited in hypothesis 5a ($\beta = 0.063$, $p < 0.001$; Table 4).

The results indicate that the company should integrate into the social structure and cognitive community of the STP, so that it can access and correctly identify the knowledge spillovers accumulated there to improve its sustainability performance (Porter, 1998; Granovetter, 1985).

Due to their degree of similarity with the company's existing cognitive bases, mental models, or knowledge resources, some of the knowledge spillovers present in an STP will be more easily exploitable, i.e. without requiring a complex absorption process by the company (Camisón *et al.*, 2018). Synergies can thus be generated between the existing and the new knowledge endowments, which can be applied to improve the company's triple bottom line sustainability performance.

In contrast, other knowledge spillovers that abound in an STP cannot be so readily exploited by the organization (Ubeda *et al.*, 2019; Claver-Cortés *et al.*, 2018; Forés and Camisón, 2016). To benefit from the impact that these more complex, tacit and novel knowledge spillovers can have on improving sustainability performance, the organization needs a well-developed absorptive capacity (Song *et al.*, 2018; Cohen and Levinthal, 1990).

This study shows that STP location does not have a direct effect on the development of this absorptive capacity, confirming the fully mediated effect of knowledge spillovers on this relationship, as established in hypothesis 5b ($\beta = 0.05$, $p < 0.001$; Table 4). Therefore, absorptive capacity has a multiplier effect on the impact of knowledge spillovers on sustainability performance, as posited in hypothesis 6 ($\beta = 0.09$, $p < 0.001$; Table 4). By increasing its absorptive capacity, the company can better combine and apply external knowledge spillovers to sustainability ends.

Additional robustness analysis confirms the validity of the conceptual model, as the direction and significance of the main relationships among constructs remain the same when distinguishing between different types of spillovers. These additional tests show that although STP location has a positive influence on the development of the different types of spillovers considered, the effect is substantially stronger on the generation and availability of scientific spillovers for companies properly embedded in the STP. This result empirically ratifies previous research (e.g. Germain *et al.*, 2022; Ubeda *et al.*, 2019) which claims that STPs are an industrial policy instrument aimed at enhancing member firms' access to the most cutting-edge and innovative scientific knowledge and differentiates the value proposition of these technology enclaves from other models of territorial agglomeration of firms, such as clusters or industrial districts (e.g. Bellandi and De Propis, 2015).

The robustness analysis also confirms that market knowledge sources have more impact on both sustainability performance and absorptive capacity than scientific and professional knowledge sources. These results confirm and extend previous studies by Diez-Martinez *et al.* (2022), Acebo *et al.* (2021) and Del Río *et al.* (2017) showing that competitors', clients' and suppliers' environmental attitudes, knowledge and practices may influence firms' sustainability performance.

Although we might have expected scientific and professional spillovers to have a greater impact on absorptive capacity than market knowledge sources, it is logical that information from firms' competitive environment is more important, considering the market-oriented nature of the innovation measurement variables in the absorptive capacity construct (Segarra-Oña *et al.*, 2016).

4.1 Theoretical implications for academia

This longitudinal study contributes to the literature on open innovation and knowledge management by demonstrating the impact of localized knowledge spillovers on a firm's sustainability performance and thus its long-term competitiveness. Our empirical evidence confirms that the firm's on-park location does matter, but does not directly impact its sustainability performance; rather, it creates the conditions for improving performance (Bellandi and De Propis, 2015), including triple bottom line sustainability performance. This study, therefore, contributes to the literature by confirming the beneficial effects of STP location on the triple bottom line of on-park companies.

This research also confirms the effects of industrial agglomerations in terms of boosting knowledge spillovers by encouraging the interaction of co-located agents and firms. Previous research also highlights the role that absorptive capacity, as a dynamic capability, can play in harnessing novel, tacit and cutting-edge external knowledge flows and applying them to improve sustainability performance. Our study with longitudinal data allows us not only to corroborate these previous findings but also to infer causality in the relationship, which cannot be established using a cross-sectional database.

On the other hand, our measure of sustainability performance holistically integrates the three widely recognized dimensions of sustainability: social, economic and environmental (e.g. Hussain *et al.*, 2018; Engert *et al.*, 2016). We, therefore, respond to calls made in recent research for further exploration of triple bottom line sustainability (e.g. Ben Arfi *et al.*, 2018; Engert *et al.*, 2016).

4.2 Implications for practitioners

This research has relevant implications for three types of practitioners: policymakers, managers of STPs and company managers. As far as policymakers and park management teams are concerned, our results show that if STPs can host numerous scientific, technological and business agents, and if these agents generate knowledge spillovers through networking processes, these parks can be a space in which companies can improve their triple bottom line sustainability performance. These findings justify public actions aimed at improving the infrastructure endowments of these spaces, the provision of high-value-added services to on-park organizations and the creation of on-park networks.

Our research also provides valuable insights for company managers, especially regarding location. Despite the globalization and digitalization of markets, location continues to play a decisive role in the ability to access high-value knowledge to improve sustainability performance. Therefore, managers should be aware that, while location alone is no guarantee of improved performance, it should be carefully selected to place the company in an environment that can provide the best market, technological, legal and consumer preference knowledge.

Given the complex nature of sustainability performance, managers should consider developing a comprehensive strategy for acquiring and integrating knowledge from both market and scientific knowledge spillovers. Lastly, the company's management should increase efforts to create internal capabilities that enable it to acquire, assimilate, transform and exploit the knowledge that flourishes in its environment.

4.3 Limitations and future lines of research

Despite its contributions to the literature, this study is not free of limitations. The first is that we use a database that only covers data from Spanish companies. STPs are a global phenomenon, so it would be interesting to test whether our hypotheses hold in culturally different environments in America, Europe, or Asia.

Although the design of the PITEC questionnaire solves problems of endogeneity between the knowledge spillovers variable and absorptive capacity, future research with this database should introduce a lag in the measurement of the knowledge spillovers variable. In future studies, it would also be interesting to employ another database in order to use alternative measures of these knowledge spillovers, such as scales previously validated in the literature.

Our study confirms that the greater the interdependence between actors and knowledge flows in an STP, the more progress on-park companies will make in terms of sustainability and innovation. Industry 4.0 technologies have been identified as transformative factors in an STP, capable of contributing to aspects such as the integrated management of global value chains, the digitalization of companies, the reduction of the gender gap in technological entrepreneurship, improved knowledge management, or the transition towards a circular economy (e.g. Sanz *et al.*, 2023; UNIDO, 2023).

Therefore, future research should, through the use of new databases and statistical procedures, assess how Industry 4.0 technologies enable companies located in an STP to respond to global challenges and increase their competitiveness. Special attention should be paid to the composition and competences of the governance and management bodies of STPs and how they act as agents of change using Industry 4.0 technologies as leverage (e.g. Sanz *et al.*, 2023). The role of public-private collaboration as a combined action capable of generating positive externalities for the economy, society and the environment should also be explored in such research (Sanz *et al.*, 2023).

Note

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Appendix
Goodness of fit and robustness analysis

1 Fit Indexes SEM

Fit statistic	Value	Description
Likelihood ratio		
chi2_ms(8)	777.066	model vs. saturated
p > chi2	0.000	
chi2_bs(15)	33160.683	baseline vs. saturated
p > chi2	0.000	
Population error		
RMSEA	0.045	Root mean squared error of approximatior
90% CI, lower bound	0.042	
upper bound	0.048	
pclose	0.999	Probability RMSEA <= 0.05
Information criteria		
AIC	2.915e+06	Akaike's information criterion
BIC	2.915e+06	Bayesian information criterion
Baseline comparison		
CFI	0.977	Comparative fit index
TLI	0.956	Tucker-Lewis index
Size of residuals		
SRMR	0.024	Standardized root mean squared residual
CD	0.045	Coefficient of determination

Source(s): Authors' own elaboration

2 Testing indirect effects with SEM: Monte Carlo tests

Partially-mediating effect of ACAP on the relationship between SPILL and SUSTAIN: Hypothesis 3

Significance testing of indirect effect (unstandardised)

Estimates	Delta	Sobel	Monte Carlo*
Indirect effect	0.318	0.318	0.318
Std. Err.	0.013	0.013	0.013
z-value	25.413	25.413	25.351
p-value	0.000	0.000	0.000
Conf. Interval	0.293 , 0.342	0.293 , 0.342	0.294 , 0.343

Source(s): Authors' own elaboration

Fully-mediating effect of SPILL on the relationship between STP and SUSTAIN: Hypothesis 5

Significance testing of indirect effect (unstandardised)

Estimates	Delta	Sobel	Monte Carlo*
Indirect effect	1.494	1.494	1.494
Std. Err.	0.048	0.048	0.048
z-value	31.398	31.398	31.381
p-value	0.000	0.000	0.000
Conf. Interval	1.401 , 1.587	1.401 , 1.587	1.401 , 1.587

Source(s): Authors' own elaboration

Partially-mediating effect of SPILL on the relationship between STP and ACAP: Hypothesis 6

Significance testing of indirect effect (unstandardised)

Estimates	Delta	Sobel	Monte Carlo*
Indirect effect	0.663	0.663	0.663
Std. Err.	0.020	0.032	0.032
z-value	33.857	21.040	20.979
p-value	0.000	0.000	0.000
Conf. Interval	0.625 , 0.701	0.601 , 0.725	0.602 , 0.726

Source(s): Authors' own elaboration

3 Robustness analysis: SEM model estimation results with an alternative measure for STP

3.1. SEM model estimation results: table

Number of obs = **47,870**
Estimation method: ml
Log likelihood = −1550181.8

		Robust				
Standardized	Coefficient	std. err.	z	P>z	[95% conf.	interval]
Structural						
SPILL						
STPMAT	0.125	0.004	26.870	0.000	0.116	0.134
_cons	1.449	0.005	285.630	0.000	1.436	1.459
SUSTAIN						
SPILL	0.508	0.004	132.970	0.000	0.500	0.515
ACAP	0.171	0.003	44.110	0.000	0.163	0.178
SIZE	0.015	0.000	4.530	0.000	0.008	0.021
EXPORTS	0.004	0.004	77.750	0.220	0.004	0.005
INDUSTRY	0.141	0.008	38.840	0.000	0.134	0.148
_cons	0.576	0.003	70.590	0.000	0.560	0.592
ACAP						
SPILL	0.409	0.004	106.310	0.000	0.401	0.401
_cons	0.643	0.007	86.970	0.000	0.629	0.629
var(e.SPILL)	0.984	0.001			0.982	0.987
var(e.SUSTAIN)	0.626	0.004			0.618	0.633
var(e.ACAP)	0.833	0.003			0.827	0.839

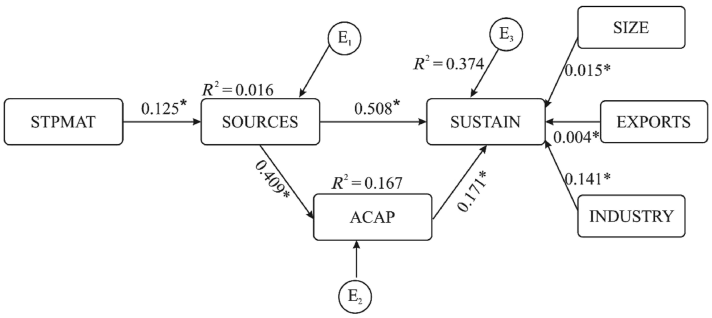
Source(s): Authors' own elaboration

3.2. Fit Indexes SEM

Fit statistic	Value	Description
Likelihood ratio		
chi2_ms(8)	762.631	model vs. saturated
p > chi2	0.000	
chi2_bs(15)	33160.922	baseline vs. saturated
p > chi2	0.000	
Population error		
RMSEA	0.044	Root mean squared error of approximation
90% CI, lower bound	0.042	
upper bound	0.047	
pclose	1.000	Probability RMSEA <= 0.05
Information criteria		
AIC	3.101e+06	Akaike's information criterion
BIC	3.101e+06	Bayesian information criterion
Baseline comparison		
CFI	0.977	Comparative fit index
TLI	0.957	Tucker-Lewis index
Size of residuals		
SRMR	0.024	Standardized root mean squared residual
CD	0.046	Coefficient of determination

Source(s): Authors' own elaboration

3.3. SEM model estimation results: graph



Source(s): Authors' own elaboration

4 Robustness analysis: SEM model estimation results extending SPILL

4.1. SEM model estimation results: table

Structural equation model — Number of obs = 47,870
Estimation method: ml
Log likelihood = −1515770.4

Standardized		Coefficient	Robust std. err.	z	P>z	[95% conf.	interval]
Structural							
MARKSPILL							
	STP	0.073	0.004	17.280	0.000	0.065	0.081
	_cons	1.446	0.020	73.230	0.000	1.408	1.485
SCIENSPILL							
	STP	0.136	0.005	27.220	0.000	0.126	0.146
	_cons	0.329	0.022	14.930	0.000	0.285	0.372
SUSTAIN							
	MARKSPILL	0.426	0.004	98.820	0.000	0.417	0.434
	SCIENSPILL	0.171	0.004	39.250	0.000	0.163	0.180
	ACAP	0.162	0.004	42.070	0.000	0.155	0.170
	SIZE	0.009	0.003	2.790	0.005	0.003	0.015
	EXPORT	0.005	0.000	88.110	0.000	0.005	0.005
	INDUSTRY	0.127	0.004	35.280	0.000	0.120	0.134
	_cons	0.451	0.008	54.590	0.000	0.435	0.467
ACAP							
	MARKSPILL	0.266	0.005	56.970	0.000	0.257	0.275
	SCIENSPILL	0.205	0.005	40.740	0.000	0.195	0.215
	_cons	0.591	0.008	74.900	0.000	0.575	0.606
var(e.MARKSPILL)		0.995	0.001	0.993	0.996	0.995	0.001
var(e.SCIENSPILL)		0.982	0.001	0.979	0.984	0.982	0.001
var(e.SUSTAIN)		0.603	0.004	0.596	0.610	0.603	0.004
var(e.ACAP)		0.830	0.003	0.824	0.836	0.830	0.003
cov(e.MARKSPILL,e.SCIENSPILL)		0.519	0.003	157.650	0.000	0.513	0.526

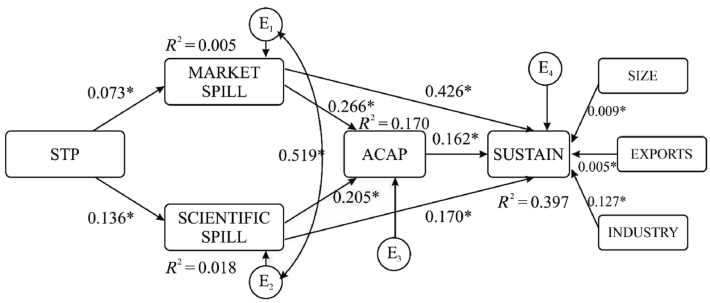
Source(s): Authors' own elaboration

4.2. Fit Indexes SEM

Fit statistic	Value	Description
Likelihood ratio		
chi2_ms(11)	1143.482	model vs. saturated
p > chi2	0.000	
chi2_bs(22)	51012.143	baseline vs. saturated
p > chi2	0.000	
Population error		
RMSEA	0.046	Root mean squared error of approximation
90% CI, lower bound	0.044	
upper bound	0.049	
pclose	0.995	Probability RMSEA <= 0.05
Information criteria		
AIC	3.032e+06	Akaike's information criterion
BIC	3.032e+06	Bayesian information criterion
Baseline comparison		
CFI	0.978	Comparative fit index
TLI	0.956	Tucker–Lewis index
Size of residuals		
SRMR	0.026	Standardized root mean squared residual
CD	0.044	Coefficient of determination

Source(s): Authors' own elaboration

4.3. SEM model estimation results: graph



Source(s): Authors' own elaboration

5 Robustness analysis: regression analysis using panel data with fixed-effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
VARIABLES	SUSTAIN	SPILL	ACAP	ACAP	SUSTAIN	ECOSUSTAIN	ENVIRONSUSTAIN	SOCIALSUSTAIN
STP	0.540**	0.470**	0.112*	0.0585	0.108	0.0559	0.0360	0.0161
	(0.0265)	(0.0380)	(0.0231)	(0.0138)	(0.00531)	(0.00524)	(0.00606)	(0.00243)
SPILL				0.0816***	0.795***	0.399***	0.183***	0.213***
				(0.238)	(0.484)	(0.463)	(0.381)	(0.398)
ACAP					0.597***	0.358***	0.107***	0.133***
					(0.125)	(0.142)	(0.0762)	(0.0848)
SIZE	2.24e−05	7.55e−06	2.42e−05**	2.60e−05**	5.19e−07	9.27e−06	−5.50e−06	−3.25e−06
	(0.00780)	(0.00432)	(0.0374)	(0.0434)	(0.000181)	(0.00616)	(−0.00656)	(−0.00348)
EXPORTS	9.24e−08***	6.41e−08***	−1.51e−08***	−2.03e−08***	5.04e−08***	1.19e−08***	2.01e−08***	1.85e−08***
	(0.00640)	(0.00730)	(−0.00407)	(−0.00675)	(0.00349)	(0.00157)	(0.00476)	(0.00393)
INDUSTRY	0.347	0.142	0.137***	0.0933	0.171	0.0305	0.0469	0.0939
	(0.0343)	(0.0231)	(0.0654)	(0.0442)	(0.0169)	(0.00574)	(0.0159)	(0.0285)
Constant	7.719***	3.916***	0.674***	0.808***	3.932***	2.797***	0.545***	0.590***
Observations	47,870	47,870	71,571	47,870	47,870	47,870	47,870	47,870
Number of ident	8,874	8,874	10,999	8,874	8,874	8,874	8,874	8,874
R-within	0.000	0.001	0.001	0.046	0.263	0.236	0.146	0.167
R-between	0.041	0.0274	0.056	0.318	0.474	0.421	0.323	0.365
R-overall	**0.028**	**0.016**	**0.043**	**0.176**	**0.364**	**0.314**	**0.235**	**0.267**

Note(s): Robust standard error in parentheses; $p < 0.05$; $p < 0.01$; $p < 0.001$

Source(s): Authors' own elaboration