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Examining green finance resilience during the COVID-19 pandemic

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Abstract
This research investigates the market response of green and environmentally focused exchange-traded funds (ETFs) to announcements by the World Health Organisation (WHO) regarding COVID-19 variants. The results show that the direction of investor responses to COVID-19 variants changed significantly over the course of the pandemic. Initial WHO announcements triggered sharp negative market responses, reflecting heightened uncertainty and investor risk aversion. However, market resilience improved as subsequent variant announcements elicited short-term positive reactions, suggesting improved investor confidence in green and environmentally focused investment assets, driven by government support and policies designed to underpin long-term sustainability. Results further illustrate ETFs' ability to mitigate systemic risks and provide portfolio diversification.

Keywords: Green finance, ESG, ETFs, pandemics, behavioural finance
JEL Classification Codes: G14, G15, G18, Q56, Q58

1. Introduction

In the aftermath of the global recession in 2008, investment in green technologies slowed as investor sentiment turned negative and access to lending became increasingly difficult (IEA, 2009). This raised questions surrounding how urgently required investments to support the green transition could be maintained consistently over this challenging economic and financial cycle. Fundamentally, it is important to understand how investor demand for green investment was influenced by global black swan events such as the COVID-19 pandemic (Naeem et al., 2022, Agoraki et al., 2023, Meehan and Corbet, 2025). Uncovering the interaction between

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sustainability and investor psychology is particularly pertinent, as such analysis helps us better understand how resilient environmentally friendly investments have become. The importance of such analysis is particularly pronounced when considering the extent to which market forces have become driven by irrational exuberance, social media activity, and the dissemination of incorrect information and news. For example, this has already been shown to affect the growth of cryptocurrencies and memecoins and sharply influence stock prices more broadly (Costola et al., 2021, Corbet et al., 2022, Bradley et al., 2024). Global ESG assets were valued at $30 trillion in 2022 according to the Global Sustainable Investment Alliance (GSIA) and are projected to surpass $40 trillion by 2030 (Diab and Mahtani, 2024). Therefore, it is vital to understand how exposure to severe market events can influence demand for investment vehicles such as exchange-traded funds (ETFs), which are central to financing the development of green technologies and the decarbonisation of the global economy.

To examine how green investments are affected by changes in the overall risk environment, we focus on the COVID-19 pandemic. Unlike studies that evaluate the relative performance of ESG assets over time by comparing them to broad market indices, our analysis relies on the precise timing of market-sensitive information releases, specifically, WHO announcements of new COVID- 19 variants. In this sense, our analysis focuses on the timing of market responses rather than the cross-section of asset returns. Since WHO announcements represent an exogenous shock to financial markets, they serve as an ideal event study for testing market reactions to extreme events. By examining the timing of official variant announcements, we isolate the returns and volatility of green assets as a distinct sub-sector within broader markets. In particular, we can show whether green ETFs are seen as a safe haven, given investors' favourable long-term view of decarbonisation, or as a luxury asset held in normal times for non-pecuniary ethical purposes. As described in Hartzmark and Sussman (2019), investors hold green investments for a broad range of reasons, where further empirical analysis is required to determine what motivations dominate such decision- making. For example, an investor may purchase a green ETF rather than a broad-market index for purely financial reasons, believing that green investments offer a superior risk-adjusted return. Alternatively, an investor could purchase green ETF shares while holding the opposing view that the risk-return trade-off is poorer in this asset class. In this case, the motivation would be based on the belief that portfolio managers should do more than maximise returns; they should also contribute to efforts to address climate change, for example, by investing in clean energy technologies or carbon sequestration. Understanding how investors make these decisions during periods of stress is particularly important because if green investments are penalised during market downturns, this would generate significant difficulties for sustained capital investment in green projects, as required to meet climate goals (OECD, 2024).

Focusing on returns around WHO announcements of new COVID-19 variants reveals how height-ended market uncertainty (in this case, stemming from unexpected global health updates) affects sustainability-focused financial assets. We conduct an event study of green ETFs, which reveals short, sharp shocks in returns. This enables us to uncover how investors updated their perception of green investments when pandemic-related information was released. Since ETFs pool diverse green and environmental assets, their prices reflect the aggregated investor

consensus on these themes in near-real time.[1]

The COVID-19 pandemic appears to have influenced green ETFs through several channels. Initially, key materials for renewable energy projects faced shipping delays or shortages due to the global COVID-19 slowdown, forcing investors to reassess timelines and cost structures (Dirzka and Acciaro, 2022). Lockdowns immediately reduced economic activity, impacted commodity extraction and consumption, and created price volatility that passed through to green technology and energy projects. On the other hand, as remote work expanded, certain green-focused technologies seized new opportunities to improve energy efficiency and reduce carbon footprints. Due to this shifting economic landscape, sustainable investing was reframed, with investors observing green assets not merely as ethical choices but as strategic hedges against long-term systemic risks, potentially boosting their appeal and valuation.

In this study, we focus specifically on the formal World Health Organisation (WHO) announcement of new variants of COVID-19, each of which represented a substantial escalation in an already unprecedented global crisis. The timing and descriptions of each WHO announcement are outlined in detail in Table 1. The events are selected to represent the date of the first declaration of the existence of a variant of concern by the WHO.

While governments enact policies to incentivise (and in some cases penalise) citizens to better adhere to green and environmental initiatives, not all countries progress simultaneously. The Global Financial Crisis and subsequent downturns, driven by geopolitical factors, have often shifted capital away from environmental projects. The depth and breadth of the COVID-19 pandemic were unprecedented, potentially diverting attention from green investment as populations adapted to the immediate economic and epidemiological challenges. We provide evidence of whether green investments serve as defensive instruments or exhibit greater volatility, thereby furthering debates surrounding their risk-return trade-offs. By isolating the effect of variant announcements on green ETF prices, this study helps to gauge whether external shocks disrupt or accelerate the attractive- ness and success of environmental-focused investment strategies. We find that green ETFs exhibited clear reactions to WHO variant announcements. In addition, we find that the size and direction of the effect changed over the course of the pandemic, with negative market reactions early in the pandemic giving way to more optimistic effects in the aftermath of later announcements.

2. Data and methodology employed

To estimate the effect of COVID-19 variant announcements on green investment, we select a sample of green ETFs based on a structured screening procedure. International ETFs are screened based on green-oriented and sustainable goals using Bloomberg and LSEG Eikon.[2]

[1] By disclosing their component stocks and weightings, green ETFs offer clear insight into how investors view various parts of the environmental sector. Further, such ETF price movements can indicate changing expectations around the long-term viability and profitability of sustainable strategies. More specifically, green ETFs provide a relatively straightforward route to ethical investing, where their demand levels can mirror investors' broader risk appetite regarding sustainability.

[2] Further screening was completed through with Seeking Alpha, ETFDB, the Financial Times, and Morningstar, however, results remained unchanged.

Table 1. Selected dummy variables relating to COVID-19 and subsequent variants

Dummy	Event Date	SARS-CoV-2 Event	Description
d_1	31-Dec-19	Unknown Pneumonia	On Dec. 31, the government in Wuhan, China, confirmed that health authorities were treating dozens of cases. Days later, researchers in China identified a new virus that had.
d_2	30-Jan-20	WHO declaration	Amid thousands of new cases in China, a "public health emergency of international concern" was officially declared by the W.H.O. China's Foreign Ministry spokeswoman said that it would continue to work with the W.H.O. and other countries to protect public health. The U.S. State Department warned travellers to avoid China.
d_3	20-Sep-20	Alpha Variant	It was estimated to be 40–80% more transmissible than the wild-type SARS-CoV-2 (with most estimates occupying the middle to the higher end of this range). It was first detected in November 2020 from a sample taken in September in the United Kingdom and began to spread quickly by mid-December, around the same time as infections surged.
d_4	18-Dec-20	Beta Variant	Phylogeographic analysis suggests this variant emerged in the Nelson Mandela Bay area in July or August 2020; however, the selected point of contact is the date of reporting by South Africa's health department on 18 December 2020.
d_5	06-Jan-21	Gamma Variant	This variant of SARS-CoV-2 was first detected by the National Institute of Infectious Diseases (NIID) of Japan on 6 January 2021 in four people who had arrived in Tokyo having visited Amazonas, Brazil, where it had subsequently been circulating undetected.
d_6	31-May-21	Delta Variant	The Delta variant was named on 31 May 2021 and had spread to over 179 countries by 22 November 2021.
d_7	24-Nov-21	Omicron Variant	Omicron (B.1.1.529) is a variant of SARS-CoV-2 first reported to the World Health Organisation (WHO) by the Network for Genomics Surveillance in South Africa on 24 November 2021. It was first detected in Botswana and has spread to become the predominant variant in circulation worldwide.

Note: Data obtained from the World Health Organization (WHO) website. Results are estimated for each pre-determined window of analysis represented above as dt, as measured in days surrounding each event listed in the above Table, including [-60,-1], [-40,-1], [-20,-1], [-10,-1], [-5,-1], [-3,-1], [0,+1] [0,+3], [0,+5], [0,+10], [0,+20], [0,+40], and [0,+60].

Data were collated for the period 1 January 2019 through 31 December 2024. Analysed ETFs were selected only if traded on at least one exchange in a G7 nation and if trading data existed for the entire sample period examined. This screening process results in ninety-four funds for the purpose of analysis. The selected time period provides substantial data before and after the COVID-19-related events under analysis. This enables an assessment of what constituted normal (non-Covid-19-influenced) trading conditions. Daily returns are estimated using rt = ln(opt/cpt−1), where opt represents the opening price on day t, and cpt−1 represents the closing price on day t-1. To provide further informational value, skewness has been identified to be beneficial for predicting returns (Jondeau et al., 2019, Langlois, 2020) sket represents the estimated daily skewness, estimated as sket = (rt − E(Rt))3/(σrt)3, which is considered due to the presence of leptokurtosis, skewness, volatility clustering, and other non-linear dependencies in the selected time series. Further, Hou et al. (2021) identified that an AR(1) process outperforms a constant when considering information share.

It has long been established that simple regression-based event studies fail to account for the time-varying volatility of asset returns (Engle, 1982, Bollerslev, 1986). In the presence of such heteroskedasticity, coefficient estimates obtained via ordinary least squares will be unbiased, but the confidence intervals will be invalid, which could lead us to reject our null hypothesis incorrectly. To account for this, we build on a generalised autoregressive conditional heteroscedasticity (GARCH) methodological framework, best suited to capturing volatility dynamics in time series (Engle, 2001). GARCH models have recently been employed to study how asset prices are affected by factors such as COVID-19, political risk, financial crises, and corporate earnings announcements (Zoungrana et al., 2023, Alim et al., 2024, Babalos et al., 2021, Salisu et al., 2025).

As the returns of the selected ETFs do not follow a normal distribution, and due to the volatility inherent in the escalation of the COVID-19 pandemic, the exponential GARCH (EGARCH) model is found to be the most suitable model specification to examine the effects of the seven events presented in Table 1 (Nelson, 1990, 1991). The EGARCH framework exploits information contained in realised volatility measures while providing a flexible leverage function that accounts for return-volatility dependence (McAleer and Hafner, 2014). A key advantage is that the EGARCH approach allows for a shock of a given magnitude to have a different effect size depending on whether it was a positive or negative shock, a feature absent from standard GARCH models (Chang and McAleer, 2017). The utilised EGARCH specification is of the form:

$$r_t = c_0 + c_1 r_{t-1} + c_2 ske_t + c_3 d_t + c_4 GARCH_t^{0.5} + \varepsilon_t \quad (1)$$

$$\varepsilon_t \sim GED(0, \sigma^2, K) \quad (2)$$

$$\ln\sigma_t^2 = c_1 + c_2 \frac{|\varepsilon_{t-1}|}{\delta_{t-1}} + c_3 \frac{\varepsilon_{t-1}}{\delta_{t-1}} + c_4 \ln\delta_{t-1}^2 \quad (3)$$

where rt−1 represents the lagged returns of green ETFs, while the COVID-19-related variant is analysed through the use of dt, representing each event described in Table 1, taking a value of one should the stated window be analysed, or zero otherwise. Results are estimated for each event using the windows, as measured[3] in days before or after t0, as [-60, -1], [-40, -1], [-20, -1], [-10, -1],[-5, -1], [-3, -1], [t0, +1] [t0, +3], [t0, +5], [t0, +10], [t0, +20], [t0, +40], and [t0,+60]. εt is assumed to follow a GED distribution, allowing for a conditional error distribution, thereby capturing fat-tail behaviour.

3. Results

When separating the key events surrounding the evolution of COVID-19 and its influence on green energy and environmental ETFs, several distinct observations can be made. At the time of the initial release of information about an as-yet-unclassified pneumonia (represented by d1), the market response is limited, with results suggesting no discernible effect on investment in green ETFs. This result is supported by the limited differences observed across the additional statistical moments analysed. However, considering the formal announcement of the existence of a global pandemic by the WHO and the subsequent evolution of the COVID-19 pandemic through the announcement of the Alpha variant (d3), sharp, negative, persistent changes in returns, skew and kurtosis are identified, along with evidence of short-term market variance. Only the Omicron variant shares similar return characteristics, while the Beta (d4), Gamma (d5), and Delta (d6) variants each exhibit opposing responses. The persistence of these results is further verified in Table 3, where each market impact is identified as short-term, dissipating within two weeks in each examined event. Such evidence suggests that green and environmental markets were responsive to varying conditions associated with the COVID-19 pandemic. However, the long-term impacts or investor perceptions that the pandemic would derail progress do not appear to have generated sustained negative sentiment towards green ETFs.

The results are further verified when considering the violin plots presented in Figure 1 and Figure 2. It is clear that in the initial phase surrounding the WHO declaration of the existence of unknown pneumonia in Wuhan, China, there is evidence of a moderate, negative response limited to three days in advance. Upon both the formal WHO declaration of the public health emergency on 30 January 2020 and the announcement of the Alpha variant in September 2020, green ETFs experienced a sharp sell-off, suggesting persistent negative price performance. However, subsequent variants, particularly those of Beta, Delta, and Gamma, exhibit the opposite response, with green ETF price performance sharply positive at the time of the WHO announcement.

[3] Various alternative methodological structures, other GARCH-family models, and windows of investigation were considered; however, those presented were identified to be most suitable using several pre-estimation, post-estimation, and goodness-of-fit testing procedures, inclusive of the Akaike information criterion (AIC), the Bayesian information criterion (BIC) and the Hannan-Quinn information criterion (HQ), respectively. For brevity, these additional results are omitted but are available from the authors upon request.

Table 2. Return differential for selected windows based on COVID-19 variant announcements

	Mean	Var	Skew	Kurt	Max	Min	1%	10%	50%	90%	99%
Event 1. Unknown Pneumonia, 31 Dec 2019											
[-10,-1]	-0.0006	0.0000	0.3711	1.1069	0.0046	-0.0052	-0.0049	-0.0031	-0.0005	0.0016	0.0045
[-3,-1]	-0.0038	0.0000	-0.1361	0.6962	0.0047	-0.0121	-0.0117	-0.0087	-0.0034	0.0002	0.0038
[-1,t0]	-0.0019	0.0000	0.7722	2.5989	0.0047	-0.0061	-0.0059	-0.0045	-0.0018	0.0004	0.0040
[t_0,+1]	0.0005	0.0000	0.5170	2.8884	0.0047	-0.0033	-0.0026	-0.0006	0.0004	0.0022	0.0042
[t_0,+3]	0.0017	0.0000	0.5259	0.2118	0.0050	-0.0005	-0.0005	-0.0001	0.0016	0.0032	0.0049
[t_0,+10]	0.0009	0.0000	0.6981	0.4466	0.0041	-0.0016	-0.0014	-0.0005	0.0006	0.0028	0.0039
Event 2. WHO Declaration, 30 Jan 2020											
[-10,-1]	0.0000	0.0000	-0.7479	-0.8852	0.0023	-0.0045	-0.0043	-0.0035	0.0010	0.0022	0.0023
[-3,-1]	-0.0011	0.0000	-0.8621	-0.5521	0.0024	-0.0085	-0.0083	-0.0063	0.0003	0.0020	0.0024
[-1,t0]	-0.0003	0.0000	-0.9629	-0.1725	0.0048	-0.0085	-0.0085	-0.0060	0.0015	0.0030	0.0047
[t_0,+1]	-0.0019	0.0000	-0.7254	-0.8269	0.0057	-0.0149	-0.0143	-0.0109	0.0012	0.0041	0.0056
[t_0,+3]	-0.0019	0.0000	-0.7254	-0.8269	0.0057	-0.0149	-0.0143	-0.0109	0.0012	0.0041	0.0056
[t_0,+10]	0.0004	0.0000	-3.4005	18.5401	0.0078	-0.0155	-0.0110	-0.0001	0.0003	0.0025	0.0064
Event 3. Alpha Variant, 20 Sept 2020											
[-10,-1]	-0.0003	0.0000	-2.8318	11.8815	0.0082	-0.0188	-0.0152	-0.0022	0.0008	0.0017	0.0063
[-3,-1]	-0.0017	0.0000	-1.8659	2.7489	0.0055	-0.0208	-0.0200	-0.0144	-0.0004	0.0032	0.0054
[-1,t0]	-0.0062	0.0002	-1.5010	1.7436	0.0063	-0.0452	-0.0429	-0.0212	0.0010	0.0042	0.0062
[t_0,+1]	-0.0028	0.0000	-1.4798	2.0440	0.0049	-0.0219	-0.0201	-0.0102	0.0001	0.0021	0.0046
[t_0,+3]	-0.003	0.0000	-0.9502	0.1190	0.0066	-0.0154	-0.0153	-0.0130	-0.0003	0.0011	0.0060
[t_0,+10]	0.0001	0.0000	1.7034	7.5742	0.0086	-0.0048	-0.0043	-0.0019	0.0000	0.0012	0.0074
Event 4. Delta Variant, 05 Oct 2020											
[-10,-1]	0.0024	0.0000	2.9054	10.0182	0.0225	-0.0037	-0.0029	-0.0005	0.0010	0.0059	0.0200
[-3,-1]	-0.0006	0.0000	1.3207	5.7089	0.0163	-0.0099	-0.009	-0.0051	0.0002	0.0020	0.0127
[-1,t0]	0.0058	0.0001	2.3206	5.8066	0.0469	-0.0028	-0.0028	-0.0019	0.0013	0.0172	0.0427
[t_0,+1]	0.0036	0.0000	2.0107	3.9798	0.0248	-0.0013	-0.0012	-0.0009	0.0017	0.0111	0.0234
[t_0,+3]	0.0030	0.0000	2.0281	3.9134	0.0190	-0.0014	-0.0012	-0.0006	0.0007	0.0089	0.0185
[t_0,+10]	0.0015	0.0000	2.8417	8.7919	0.0118	-0.0010	-0.0008	0.0001	0.0009	0.0036	0.0104
Event 5. Beta Variant, 18 Dec 2020											
[-10,-1]	0.0010	0.0000	1.3302	1.1859	0.0060	-0.0011	-0.0010	-0.0007	0.0003	0.0037	0.0055
[-3,-1]	0.0012	0.0000	2.4650	10.2637	0.0216	-0.0058	-0.0057	-0.0020	0.0001	0.0046	0.0169
[-1,t0]	0.0005	0.0000	1.8494	7.7608	0.0154	-0.0064	-0.0063	-0.0024	0.0002	0.0032	0.0126
[t_0,+1]	0.0000	0.0000	-0.4551	4.5560	0.0151	-0.0163	-0.0154	-0.0027	0.0001	0.0054	0.0134
[t_0,+3]	-0.0006	0.0000	0.9499	3.7423	0.0154	-0.0112	-0.0110	-0.0046	-0.0006	0.0014	0.0135
[t_0,+10]	0.0008	0.0000	2.0783	4.6341	0.0073	-0.0021	-0.0018	-0.0006	0.0001	0.0026	0.0069
Event 6. Gamma Variant, 06 Jan 2021											
[-10,-1]	0.0010	0.0000	0.7120	1.9439	0.0059	-0.0038	-0.0029	-0.0005	0.0006	0.0040	0.0056
[-3,-1]	0.0010	0.0000	1.3131	3.5070	0.0130	-0.0058	-0.0053	-0.0016	0.0005	0.0060	0.0112
[-1,t0]	0.0020	0.0001	3.2757	10.9939	0.0387	-0.0043	-0.0040	-0.0031	-0.0011	0.0058	0.0364
[t_0,+1]	0.0045	0.0002	3.0385	11.0014	0.0600	-0.0043	-0.0037	-0.0022	-0.0010	0.0175	0.0495
[t_0,+3]	0.0041	0.0001	2.6535	8.8754	0.0437	-0.0043	-0.0035	-0.0012	-0.0005	0.0138	0.0353
[t_0,+10]	0.0014	0.0000	1.6073	1.9205	0.0111	-0.0024	-0.0023	-0.0015	0.0001	0.0064	0.0109
Event 7. Omicron Variant, 24 Nov 2021											
[-10,-1]	-0.0009	0.0000	0.9478	5.4869	0.0068	-0.0055	-0.0055	-0.0030	-0.0007	0.0004	0.0053
[-3,-1]	-0.0047	0.0000	1.1626	5.8363	0.0135	-0.0142	-0.0141	-0.0104	-0.0046	-0.0010	0.0092
[-1,t0]	-0.0052	0.0000	-2.2930	9.2238	0.0038	-0.0272	-0.0230	-0.0087	-0.0045	-0.0001	0.0031
[t_0,+1]	0.0010	0.0000	0.0576	3.0940	0.0151	-0.0184	-0.0148	-0.0028	-0.0002	0.0112	0.0148
[t_0,+3]	-0.0015	0.0000	-0.6795	0.5317	0.0109	-0.0174	-0.0152	-0.0089	0.0008	0.0031	0.0091
[t_0,+10]	-0.0019	0.0000	-1.2609	0.7670	0.0037	-0.0143	-0.0139	-0.0099	0.0009	0.0018	0.0035

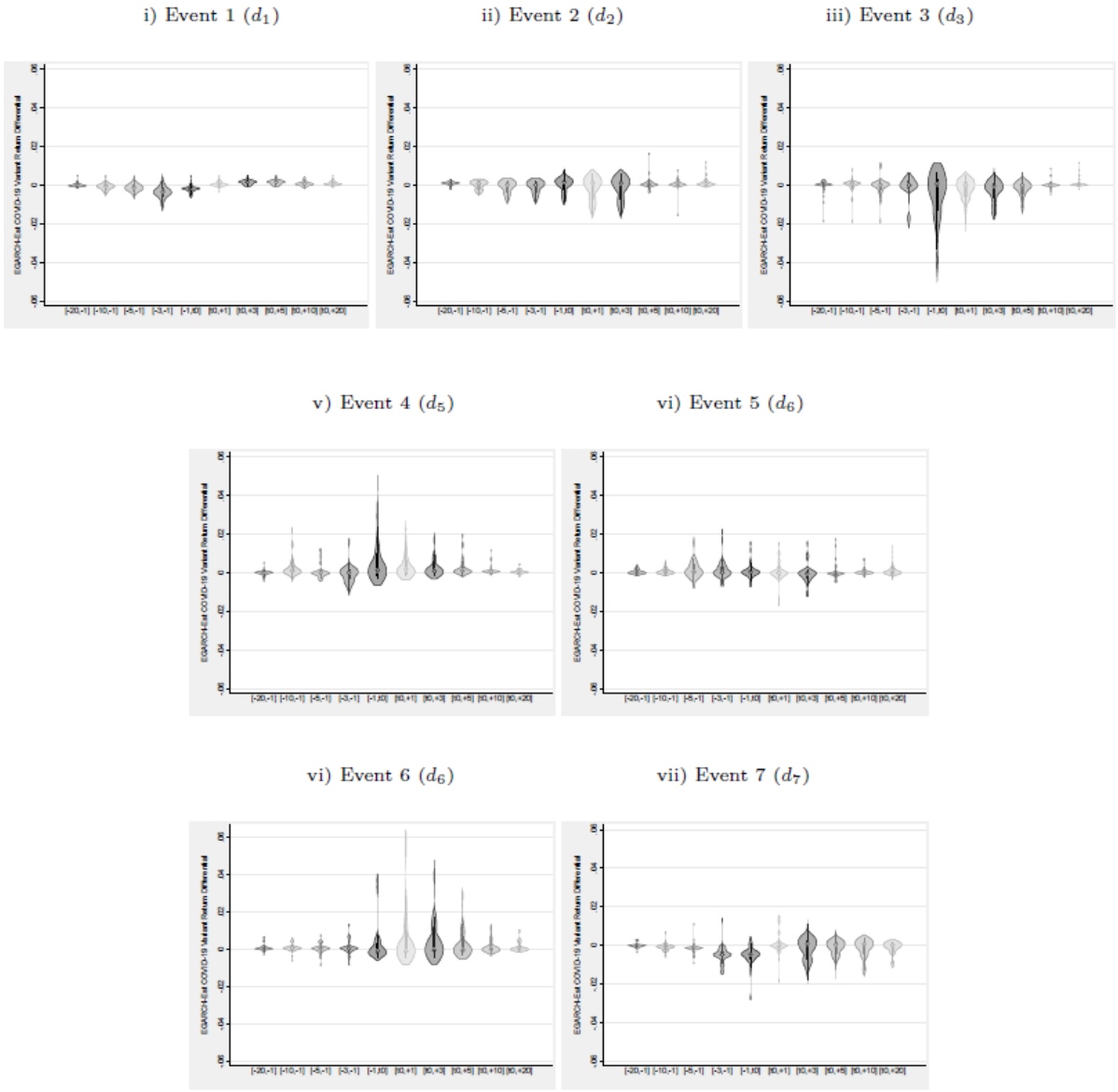
Note: To obtain the above-presented results, we build GARCH methodological structure of the form: $r_t = c_0 + c_1 r_{t-1} + c_2 ske_t + c_3 d_t + c_4 GARCH_t^{0.5} + \varepsilon_t$ where r_{t-1} represents the lagged green-focused ETF returns, while the COVID-19-related variant is analysed through the use of d_t, representing each event described in Table 1, taking a value of unity should the stated window be analysed, or zero otherwise.

Table 3. Return differential for windows covering before and after COVID-19 variant announcements

	Mean	Var	Skew	Kurt	Max	Min	1%	10%	50%	90%	99%
Event 1. Unknown Pneumonia, 31 Dec 2019											
[-10,-1]	-0.0006	0.0000	0.3711	1.1069	0.0046	-0.0052	-0.0049	-0.0031	-0.0005	0.0016	0.0045
[-3,-1]	-0.0038	0.0000	-0.1361	0.6962	0.0047	-0.0121	-0.0117	-0.0087	-0.0034	0.0002	0.0038
[-1,t0]	-0.0019	0.0000	0.7722	2.5989	0.0047	-0.0061	-0.0059	-0.0045	-0.0018	0.0004	0.0040
[t_0,+1]	0.0005	0.0000	0.5170	2.8884	0.0047	-0.0033	-0.0026	-0.0006	0.0004	0.0022	0.0042
[t_0,+3]	0.0017	0.0000	0.5259	0.2118	0.0050	-0.0005	-0.0005	-0.0001	0.0016	0.0032	0.0049
[t_0,+10]	0.0009	0.0000	0.6981	0.4466	0.0041	-0.0016	-0.0014	-0.0005	0.0006	0.0028	0.0039
Event 2. WHO Declaration, 30 Jan 2020											
[-10,-1]	0.0000	0.0000	-0.7479	-0.8852	0.0023	-0.0045	-0.0043	-0.0035	0.0010	0.0022	0.0023
[-3,-1]	-0.0011	0.0000	-0.8621	-0.5521	0.0024	-0.0085	-0.0083	-0.0063	0.0003	0.0020	0.0024
[-1,t0]	-0.0003	0.0000	-0.9629	-0.1725	0.0048	-0.0085	-0.0085	-0.0060	0.0015	0.0030	0.0047
[t_0,+1]	-0.0019	0.0000	-0.7254	-0.8269	0.0057	-0.0149	-0.0143	-0.0109	0.0012	0.0041	0.0056
[t_0,+3]	-0.0019	0.0000	-0.7254	-0.8269	0.0057	-0.0149	-0.0143	-0.0109	0.0012	0.0041	0.0056
[t_0,+10]	0.0004	0.0000	-3.4005	18.5401	0.0078	-0.0155	-0.0110	-0.0001	0.0003	0.0025	0.0064
Event 3. Alpha Variant, 20 Sept 2020											
[-10,-1]	-0.0003	0.0000	-2.8318	11.8815	0.0082	-0.0188	-0.0152	-0.0022	0.0008	0.0017	0.0063
[-3,-1]	-0.0017	0.0000	-1.8659	2.7489	0.0055	-0.0208	-0.0200	-0.0144	-0.0004	0.0032	0.0054
[-1,t0]	-0.0062	0.0002	-1.5010	1.7436	0.0063	-0.0452	-0.0429	-0.0212	0.0010	0.0042	0.0062
[t_0,+1]	-0.0028	0.0000	-1.4798	2.0440	0.0049	-0.0219	-0.0201	-0.0102	0.0001	0.0021	0.0046
[t_0,+3]	-0.003	0.0000	-0.9502	0.1190	0.0066	-0.0154	-0.0153	-0.0130	-0.0003	0.0011	0.0060
[t_0,+10]	0.0001	0.0000	1.7034	7.5742	0.0086	-0.0048	-0.0043	-0.0019	0.0000	0.0012	0.0074
Event 4. Delta Variant, 05 Oct 2020											
[-10,-1]	0.0024	0.0000	2.9054	10.0182	0.0225	-0.0037	-0.0029	-0.0005	0.0010	0.0059	0.0200
[-3,-1]	-0.0006	0.0000	1.3207	5.7089	0.0163	-0.0099	-0.009	-0.0051	0.0002	0.0020	0.0127
[-1,t0]	0.0058	0.0001	2.3206	5.8066	0.0469	-0.0028	-0.0028	-0.0019	0.0013	0.0172	0.0427
[t_0,+1]	0.0036	0.0000	2.0107	3.9798	0.0248	-0.0013	-0.0012	-0.0009	0.0017	0.0111	0.0234
[t_0,+3]	0.0030	0.0000	2.0281	3.9134	0.0190	-0.0014	-0.0012	-0.0006	0.0007	0.0089	0.0185
[t_0,+10]	0.0015	0.0000	2.8417	8.7919	0.0118	-0.0010	-0.0008	0.0001	0.0009	0.0036	0.0104
Event 5. Beta Variant, 18 Dec 2020											
[-10,-1]	0.0010	0.0000	1.3302	1.1859	0.0060	-0.0011	-0.0010	-0.0007	0.0003	0.0037	0.0055
[-3,-1]	0.0012	0.0000	2.4650	10.2637	0.0216	-0.0058	-0.0057	-0.0020	0.0001	0.0046	0.0169
[-1,t0]	0.0005	0.0000	1.8494	7.7608	0.0154	-0.0064	-0.0063	-0.0024	0.0002	0.0032	0.0126
[t_0,+1]	0.0000	0.0000	-0.4551	4.5560	0.0151	-0.0163	-0.0154	-0.0027	0.0001	0.0054	0.0134
[t_0,+3]	-0.0006	0.0000	0.9499	3.7423	0.0154	-0.0112	-0.0110	-0.0046	-0.0006	0.0014	0.0135
[t_0,+10]	0.0008	0.0000	2.0783	4.6341	0.0073	-0.0021	-0.0018	-0.0006	0.0001	0.0026	0.0069
Event 6. Gamma Variant, 06 Jan 2021											
[-10,-1]	0.0010	0.0000	0.7120	1.9439	0.0059	-0.0038	-0.0029	-0.0005	0.0006	0.0040	0.0056
[-3,-1]	0.0010	0.0000	1.3131	3.5070	0.0130	-0.0058	-0.0053	-0.0016	0.0005	0.0060	0.0112
[-1,t0]	0.0020	0.0001	3.2757	10.9939	0.0387	-0.0043	-0.0040	-0.0031	-0.0011	0.0058	0.0364
[t_0,+1]	0.0045	0.0002	3.0385	11.0014	0.0600	-0.0043	-0.0037	-0.0022	-0.0010	0.0175	0.0495
[t_0,+3]	0.0041	0.0001	2.6535	8.8754	0.0437	-0.0043	-0.0035	-0.0012	-0.0005	0.0138	0.0353
[t_0,+10]	0.0014	0.0000	1.6073	1.9205	0.0111	-0.0024	-0.0023	-0.0015	0.0001	0.0064	0.0109
Event 7. Omicron Variant, 24 Nov 2021											
[-10,-1]	-0.0009	0.0000	0.9478	5.4869	0.0068	-0.0055	-0.0055	-0.0030	-0.0007	0.0004	0.0053
[-3,-1]	-0.0047	0.0000	1.1626	5.8363	0.0135	-0.0142	-0.0141	-0.0104	-0.0046	-0.0010	0.0092
[-1,t0]	-0.0052	0.0000	-2.2930	9.2238	0.0038	-0.0272	-0.0230	-0.0087	-0.0045	-0.0001	0.0031
[t_0,+1]	0.0010	0.0000	0.0576	3.0940	0.0151	-0.0184	-0.0148	-0.0028	-0.0002	0.0112	0.0148
[t_0,+3]	-0.0015	0.0000	-0.6795	0.5317	0.0109	-0.0174	-0.0152	-0.0089	0.0008	0.0031	0.0091
[t_0,+10]	-0.0019	0.0000	-1.2609	0.7670	0.0037	-0.0143	-0.0139	-0.0099	0.0009	0.0018	0.0035

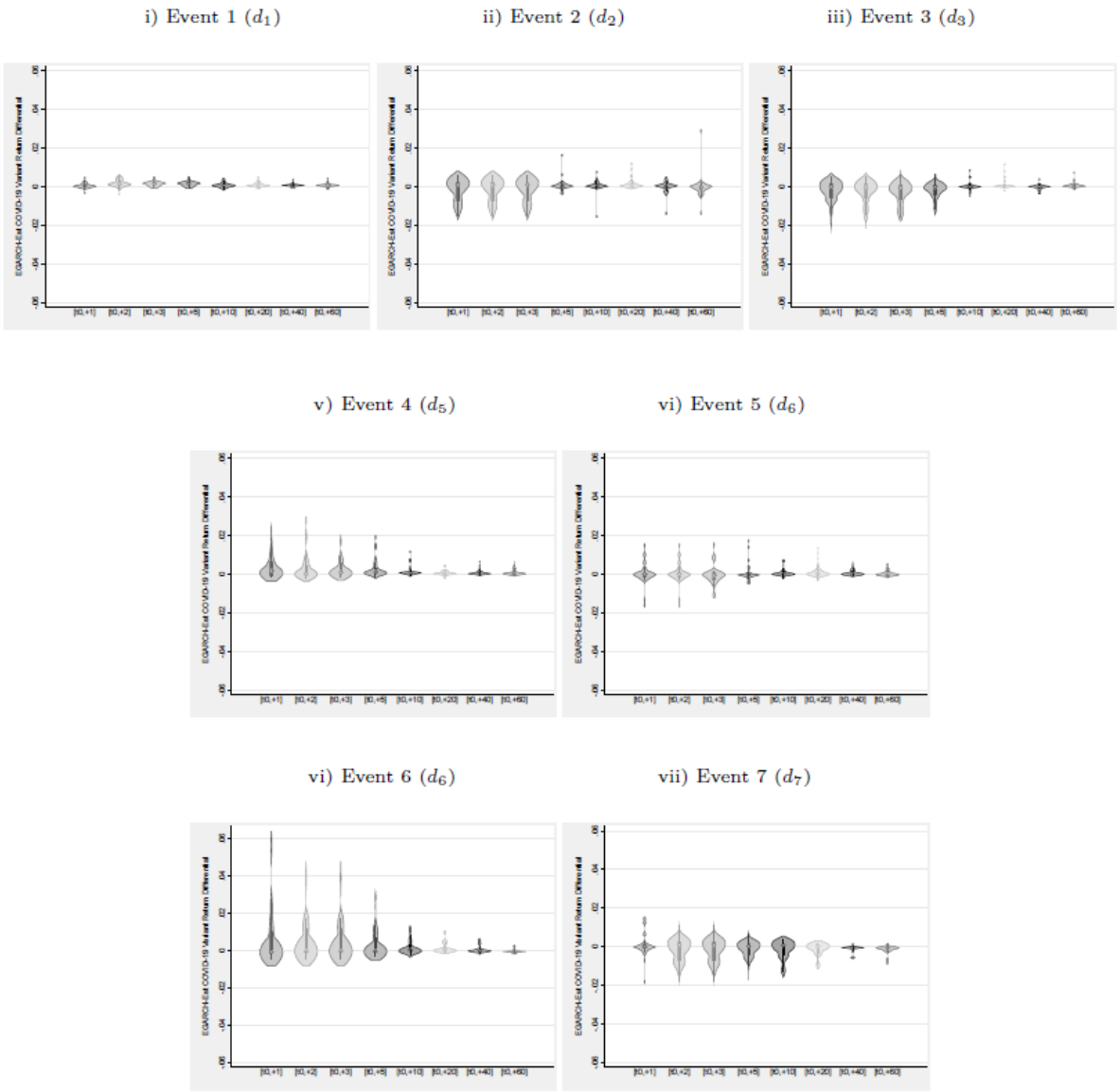
Note: To obtain the above-presented results, we build GARCH methodological structure of the form: rt = c0 + c1rt−1 + c2sket + c3dt + c4GARCH0.5 + εt where rt−1 represents the lagged green-focused ETF returns, while the COVID-19-related variant is analysed through the use of dt, representing each event described in Table 1, taking a value of unity should the stated window be analysed, or zero otherwise.

Figure 1. Violin plots of selected windows analysed based on COVID-19 variant announcements



Note: To obtain the above-presented results, we build GARCH methodological structure of the form: $r_t = c_0 + c_1 r_{t-1} + c_2 ske_t + c_3 d_t + c_4 GARCH_t^{0.5} + \varepsilon_t$ where r_{t-1} represents the lagged green-focused ETF returns, while the COVID-19-related variant is analysed through the use of d_t, representing each event described in Table 1, taking a value of unity should the stated window be analysed, or zero otherwise. The scale of the vertical axes was maintained across all the Figures presented above to improve comparability. The scale was selected based on the maximum and minimum values across all presented results. Various alternative methodological structures, other GARCH-family models, and windows of investigation were considered; however, for brevity of presentation, these additional results are omitted but are available from the authors upon request.

Figure 2. Violin plots of windows inclusive of period before and after COVID-19 variant announcements



Note: To obtain the above-presented results, we build GARCH methodological structure of the form: $r_t = c_0 + c_1 r_{t-1} + c_2 ske_t + c_3 d_t + c_4 GARCH_t^{0.5} + \varepsilon_t$ where r_{t-1} represents the lagged green-focused ETF returns, while the COVID-19-related variant is analysed through the use of d_t, representing each event described in Table 1, taking a value of unity should the stated window be analysed, or zero otherwise. The scale of the vertical axes was maintained across all the Figures presented above to improve comparability. The scale was selected based on the maximum and minimum values across all presented results. Various alternative methodological structures, other GARCH-family models, and windows of investigation were considered; however, for brevity of presentation, these additional results are omitted but are available from the authors upon request.

We must consider why different variant announcements elicited opposite responses across green and environmentally focused ETFs. Initially, the pandemic sparked fear and uncertainty, triggering a broad sell-off, including that of green ETFs, as investors fled to safety. For subsequent variants, particularly Delta and Gamma, positive responses reflect investor adaptation and resilience as fears eased and vaccine rollouts or mitigative measures gained traction. Issues with supply chains alleviated over time, along with improved vaccine rollouts, which increased investor confidence and supported market resilience. Further, the initial negative responses stemmed from uncertainty and limited data. By the time that later variants emerged, investors had learned from prior shocks, reducing the magnitude of the market's negative responses. Positive reactions could also reflect the view that such announcements provided clarity, reducing ambiguity about the pandemic's trajectory.

At a more basic level, remote work trends and increased digitalisation during the pandemic created opportunities for improved energy-efficient work practices and carbon footprint-reduction technologies, driven by work-from-home policies and other distancing measures (Le Quéré et al., 2020). These factors were likely viewed by markets as positive for green investment. International organisations such as the United Nations and the International Monetary Fund advocated a "green recovery" from COVID-19, urging countries to align recovery spending with climate goals. Further, the pandemic drove governments to adopt "green stimulus" measures emphasising green-focused recovery plans such as the EU's Green Deal and the Biden administration's climate agenda. Several countries expanded funding for green initiatives alongside subsidies and tax incentives for renewable energy projects during the pandemic.[4] Policies like investment tax credits for solar and wind projects likely signalled long-term government commitment to green transitions, driving positive sentiment in green ETFs. Green measures were a key part of landmark legislation in the US, such as the Inflation Reduction Act in 2022, which introduced a scheme allowing taxpayers to deduct part of the cost of renewable energy upgrades from their income taxes. This reinforced the view of green sectors as crucial for post-pandemic recovery, thereby attracting investors, particularly amid heightened public awareness of environmental and health issues stemming from the pandemic, which accelerated shifts toward sustainable products and services. Regulatory initiatives supporting ESG investments gained traction during the pandemic. For example, the EU's Sustainable Finance Disclosure Regulation (SFDR) imposed requirements for fund managers to disclose ESG metrics, which improved transparency and likely encouraged greater inflows into green ETFs, boosting their market responses to variant announcements. Some governments temporarily relaxed regulations to fast-track renewable energy projects or reduce bureaucratic barriers to green technology adoption. This flexibility likely contributed to market optimism about the accelerated implementation of green initiatives, reflected in the positive

[4] The momentum of international climate agreements did not appear to be hampered during the COVID-19 pandemic as countries such as China announced carbon neutrality targets (for example, by 2060), while the US rejoined the Paris Agreement in early 2021. These commitments reassured markets that green initiatives remained high on the political agenda, positively impacting green ETFs when new COVID-19 variants were announced.

ETF responses in later periods of our sample.

4. Concluding remarks

Our results demonstrate that green and environmentally focused ETFs were affected by public announcements of new COVID-19 variants, with the magnitude and direction of the effect changing as the pandemic evolved. This is evidenced by dynamic responses to later phases, indicating that investor sentiment was supported by governments' efforts to mitigate the pandemic's severe economic impact. Our results are therefore consistent with research on the importance of investor sentiment in explaining flows into green investment products (de Sousa-Gabriel et al., 2024). As the pandemic evolved, so did that of digital and green-focused corporate practices, while reducing epidemiological impacts also served to change several dynamics associated with the global carbon footprint. This highlights the evolving role of green investments, not only providing a potential defensive mechanism for portfolios against black swan events but also presenting evidence of sectoral resilience in the face of severe global economic shocks, albeit heavily supported by government policy. Fundamentally, it is important to note that negative investor responses to the COVID-19 pandemic and subsequent variants appear to have abated during the same period that governments announced policies to support a green-focused economic recovery. This evidence highlights the role that government responses and public information releases can play in shaping investor sentiment towards green and environmentally focused firms during periods of stress.

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