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Black swan events and COVID-19 outbreak: Sector level evidence from the US, UK, and European stock markets

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A B S T R A C T

Studies investigating the impact of coronavirus outbreak at the sector (industry) level are scant and focus on the USA market. We examine this issue for the US, UK, and the European stock markets, using endogenous structural break models and factor-augmented event study methodology by identifying the critical events. We find that the impact of coronavirus outbreak to the extent of black swan events is visible in March and, till the end of March 2020, the investors had limited opportunities for investment except for a few sectors in the US, UK, and Europe due to black swan events. Specifically, we find some stocks in consumer staples, healthcare, telecommunications, utilities, and financials were the attention-seekers and different sectors in our sample countries had different reactions to the outbreak. Overall, the analysis provides the reasons for panic buy and sell.

1. Introduction

Examining the impact of coronavirus (COVID-19) outbreak has seen exponential growth in the number of studies. The availability of high-frequency data and time-series techniques have helped researchers exploring this issue at a great length. An overview of these studies suggests that a large volume of studies have analysed the coronavirus impact at the aggregate levels. Yet, there is a void for a disaggregated analysis, which helps investors and policymakers to make more informed decisions. In this paper, we fill this gap in the literature. First, we briefly summarize the recent related studies.

Sharif et al. (2020) find the impact of a pandemic on the geopolitical dimensions of the US economy than the stock market. Corbet, Hou, et al. (2020) examine the reputational-based contagion of coronavirus outbreak and analyse the sharp, dynamic, and new correlation channels for the firms which have Corona names. Ali et al. (2020) trace the spread of Coronavirus and report its impact on financial markets, including commodities. Corbet, Larkin, and Lucey (2020) examine the volatility relationship between Chinese stock markets and the bitcoin during the peak of pandemic and report the significant correlation between the two. Al-Awadhi et al. (2020) find the considerable impact of the coronavirus cases and deaths on the stock returns of Chinese firms. Zhang et al. (2020) exhibit the significant influence of the pandemic on the ten major economies, including the US, China, and Italy. Mnif et al. (2020) examine the herding biases in cryptocurrency using fractals before and after the coronavirus outbreak and report a positive impact on the market efficiency of cryptocurrency.

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Table 1
List of events identified using multiple structural break model.

Even Date	Events	Source
February 03	The first coronavirus death was reported outside China.	NYT
February 19	Hundreds left the quarantined Diamond Princess cruise	NYT
February 21	A secret church group in South Korea was linked to the surge in infections	TG
February 24	The virus spread to Italy, Korea and Iran.	TG
February 27	750 new cases were reported outside China and spread to 46 countries	TG
March 04	Cases neared 93000 and had spread to 81 countries with South Korea, Italy, and Iran as hotspots.	TG
March 05	The US approved widespread testing and calls for an interest rate cut.	NYT
March 09	The stock market fell by more than 7% due to the pandemic.	TG
March 12	The stock market of the USA saw the biggest fall since 1987 Black Monday. DJIA fell by more than 10%.	Bloomberg
March 16	US stock market DJIA recorded the fall by 30%	NYT
March 18	The global coronavirus infection crosses 200,000.	NYT & TG
March 19	China reported zero local infections and virus had spread in the UK and Europe	NYT & TG

Note: TG: The Guardian, NYT: The New York Times.

Okorie and Lin (2020) examine fractal-based contagion effects of COVID-19 on stock markets. Using Detrended Moving Cross-Correlation Analysis and Detrended Cross-Correlation Analysis, they find the significant impact of COVID-19 on the stock market. Akhtaruzzaman et al. (2020) find the contagion effect between China and G7 during the COVID-19 outbreak and report the evidence of financial contagion and increased hedge ratios. Shehzad et al. (2020) find the impact of COVID-19 on the US and Japan market returns. Erdem (2020) shows the significant effect of coronavirus outbreak on global financial markets. Cepoi (2020) examine the Coronavirus related news in the top six most affected countries by the pandemic and find that the fake news had the most negative nonlinear on the lower and middle quantiles. Le et al. (2020) provide the evidence of how one can reduce the impact of news shocks on the macroeconomic variables using the rational expectations framework. Harjoto et al. (2020) report that the stimulus package announced by the US government amid coronavirus outbreak was enjoyed more by the large firms than the small ones. Hartley and Rebucci (2020, pp. 1–22) analyse the influence of quantitative easing (QE) announcements made by the central banks of developed and emerging economies to tackle the coronavirus outbreak. They find that the impact of QE was more substantial for emerging economies than the developed markets. Xu and Lien (2020) provide evidence on the impact of trade war between China and the US and how it has depreciated the Chinese currency and may deepen the impact further due to the coronavirus outbreak. In a relevant study, Ahmad et al. (2021) examine the spillover characteristics of US equities with options-implied volatilities of stock market, crude oil and gold. Their study finds that the outbreak has strenghened the spillover between sectoral equities and implied volatilities.

Overall, it is apparent from the above discussion that there is a limited scope to conduct the aggregate level analysis as studies have already covered a great length and the only area which may seek the attention of concerned regulators and investors is to analyse the impact of coronavirus outbreak at the disaggregated level. In this regard, limited studies examining the sector level returns have mostly focused on US markets. For example, Haroon and Rizvi (2020) analyse the effects of coronavirus outbreak at the sectoral level for the world and the US and report that the pandemic related news has indeed increased the volatility of these indices. Goodell and Huynh (2020) analyse the effects of COVID-19 on 23 US sectors using event study approach by taking into account the trading patterns of the US legislators. They identify positive (negative) abnormal returns for medical (restaurants), pharmaceuticals (hotels, and motels).

In this study, we extend the limited sectoral studies to analyse the impact of coronavirus outbreak events on advanced equities markets by taking into account major sectors of not only the US but also the UK and Europe until March 31, 2020. We select these developed countries because the first wave of the pandemic was evident for Europe, the USA, and the UK. We majorly focus on the sectors of these countries and investigate whether the coronavirus related incidences have generated black swan events or has remained a grey swan event. We do not include emerging markets because, at the time of sample selection, the impact was more visible in advanced economies. Our study adopts a two-step procedure. In the first step, we work on the identification of significant events related to the pandemic. For the second step, we work on those events using the factor model (Fama and French, 1992; Fama and French 1993) augmented event-study methodology To our knowledge, our paper is the first analysis focusing on the impact of Coronavirus on the sectors of the US, UK, and Europen sectors in a single analysis. The sectoral analysis also makes our approach unique in global contexts. In light of the literature mentioned above, in this study, we look at pandemic distress from a financial market perspective. We want to examine whether the stock market pandemic provided the scope for arbitrage and safe haven. Although our study is different, yet it is close to Haroon and Rizvi (2020) and Goodell and Huynh (2020) who focus on US sectors only, while we analyse the US. UK and European markets and compare our findings with these studies.

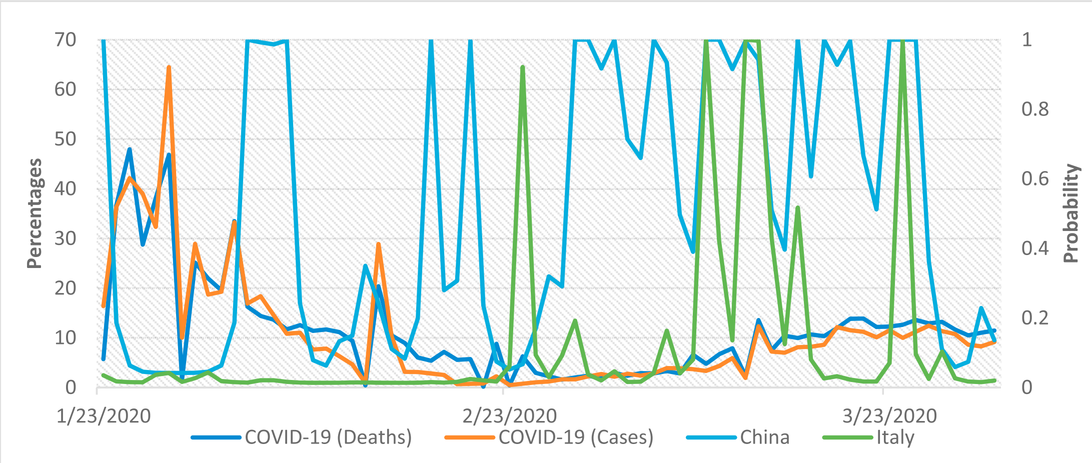
The rest of the study is organised as follows. Section 2 outlines the data and methodology. Section 3 focuses on analysing results with connectedness analysis discussed in section 4. Section 5 concludes the study.

2. Data and methodology

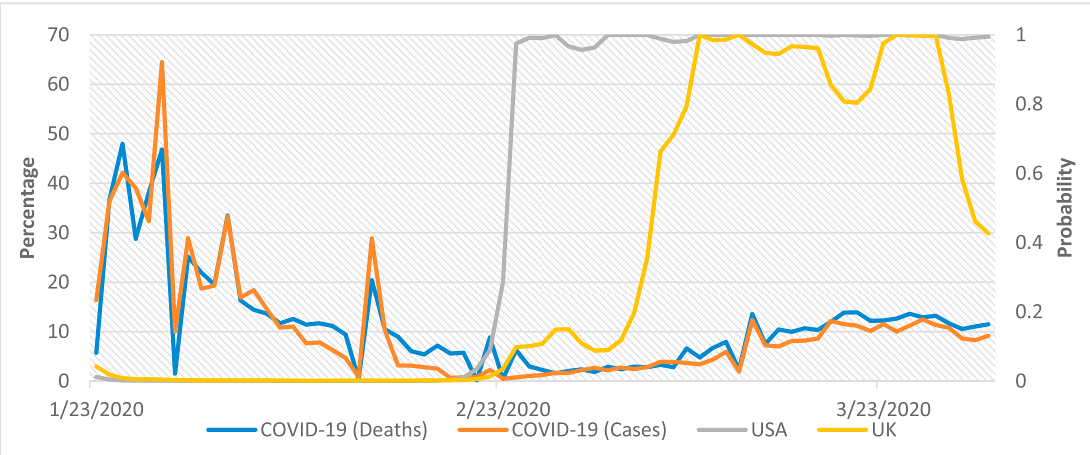
We utilize the firm level daily data to draw the sectoral inferences. To do this, we first obtain stock prices of the constituents of (S&P-500 (Standard and Poor's) for the USA, FTSE-350 (Financial Times Stock Exchange) for the UK and S&P Europe (186 constituents) of representative indices.

The sample sectors are IT (Information technology) ConsD (Consumer Discretionary), ConsS (Consumer Staples), Health (Healthcare), Fin. (Financials), Tele. (Telecommunications), Energy (Oil & Gas), Indus. (Industrials), Utilities, Estate (Real Estate), Mater.

Panel A: China and Italy



Panel B: USA and UK



Note: the above plot shows the smoothed probabilities of bear market for the period January 23 2020 till March 31 2020. COVID-19 (Deaths) and COVID-19 (Cases) exhibit the global growth of Coronavirus deaths and cases. China and Italy are the stock indices returns.

Fig. 1. Growth in Coronavirus Cases and Deaths and Bearish Stock Markets of China, Italy, USA and UK
Note: the above plot shows the smoothed probabilities of bear market for the period January 23, 2020 till March 31, 2020. COVID-19 (Deaths) and COVID-19 (Cases) exhibit the global growth of Coronavirus deaths and cases. China and Italy are the stock indices returns.

(Materials), Misc. (All other subsectors). The sample period is from May 1, 2019, to March 31, 2020. We start our analysis from May 1, 2019, as it allows us to have a higher number of normal days, which is a pre-requisite for the event-study analysis. We use the three-factor models of Fama and French to calculate the abnormal returns from the constituents (S&P-500 (Standard and Poor's) for the USA, FTSE-350 (Financial Times Stock Exchange) for the UK, S&P Europe (186 constituents) of representative indices. We source the factors from Fama and French's webpage.[1] The cases and deaths of novel Coronavirus are collected from the *John Hopkins Coronavirus Resource Centre*.[2]

To identify the significant events, we adopt a three-step procedure. In the first step, we explore the linear and nonlinear endogenous structural break models. We begin with the linear endogenous structural break given by the Bai and Perron (2003, hereafter BP), which introduces the general-to-specific estimation procedure under a linear framework. The key feature of the BP test is that it allows us to

[1] http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html#International (Accessed on 10th May 2020).
[2] https://github.com/CSSEGISandData/COVID-19 (accessed on 15th April 2020).

Table 2
AAR and CAAR of US sectors (±3 days).

	Sectors	IT	ConsD	ConsS.	Health	Fin.	Tele.	Energy	Indus.	Utilities	Estate	Mater.	Misc.
03-02-2020	AAR	**0.003**	0.000	−0.001	−0.001	**0.005**	**−0.014**	**−0.010**	0.000	**0.005**	**−0.004**	**0.012**	−0.007
	t-test	2.276	−0.149	−0.206	−0.997	4.825	−3.427	−2.625	−0.157	3.972	−2.351	4.639	−1.030
	CAAR	−0.001	0.004	**0.003**	0.005	**0.023**	−0.004	0.009	**0.010**	**0.006**	0.001	**0.040**	−0.003
	t-test	−0.251	0.732	0.426	0.790	5.678	−0.618	1.043	2.116	1.949	0.130	5.113	−0.191
19-02-2020	AAR	**0.005**	0.000	**−0.004**	**0.002**	0.001	0.001	**0.013**	**−0.005**	**−0.008**	**−0.016**	0.000	−0.003
	t-test	3.408	0.318	−2.340	1.819	0.679	0.332	3.778	−4.497	−6.488	−5.352	−0.179	−0.893
	CAAR	**0.013**	0.006	0.009	0.008	0.024	0.001	−0.002	**0.016**	**0.020**	**0.034**	0.011	−0.002
	t-test	3.077	1.063	1.527	1.688	5.278	0.037	−0.175	4.071	4.307	5.651	1.122	−0.081
21-02-2020	AAR	**−0.002**	−0.002	**0.006**	**0.009**	0.001	0.004	−0.002	**0.009**	0.002	**0.011**	**0.012**	0.005
	t-test	−1.888	−1.196	3.889	5.633	1.074	1.874	−0.849	5.240	0.906	8.608	3.146	0.957
	CAAR	**0.024**	−0.004	−0.006	0.006	**0.022**	**0.023**	−0.013	**0.019**	**−0.025**	**−0.013**	0.013	−0.007
	t-test	5.205	−0.572	−0.836	0.763	4.866	2.109	−1.254	3.390	−5.489	−2.198	1.114	−0.273
24-02-2020	AAR	**0.009**	0.000	0.000	−0.001	**0.005**	**0.010**	**−0.014**	**0.008**	**−0.002**	0.001	0.005	0.002
	t-test	5.664	−0.028	−0.095	−0.188	3.514	5.308	−3.943	5.002	−1.663	0.599	1.203	0.490
	CAAR	**0.038**	0.004	**−0.013**	0.012	**0.025**	**0.012**	−0.020	**0.028**	**−0.061**	**−0.049**	0.012	−0.018
	t-test	6.416	0.506	−2.072	1.486	4.937	4.034	−1.741	4.199	−14.717	−6.718	1.174	−0.608
27-02-2020	AAR	**0.013**	**0.012**	**−0.009**	0.004	**0.004**	−0.011	−0.004	**0.010**	**−0.028**	**−0.035**	−0.003	−0.005
	t-test	4.302	3.776	−3.355	1.128	1.952	−1.496	−0.614	3.308	−8.026	−7.457	−0.890	−0.494
	CAAR	**0.031**	−0.003	−0.008	0.001	0.006	0.020	−0.002	0.010	**−0.060**	**−0.053**	**0.022**	−0.008
	t-test	4.161	−0.374	−1.123	0.162	1.197	1.591	−0.180	1.163	−10.482	−6.882	2.445	−0.323
04-03-2020	AAR	**−0.013**	**−0.010**	**0.021**	**0.016**	**−0.007**	**0.017**	**−0.016**	0.002	**0.038**	**0.019**	0.005	−0.008
	t-test	−6.405	−3.802	7.018	4.082	−3.024	2.363	−4.036	0.835	15.540	7.657	1.397	−0.698
	CAAR	0.006	0.001	**0.030**	0.016	**−0.039**	0.014	**−0.214**	0.006	**−0.033**	**−0.055**	**0.030**	−0.018
	t-test	0.630	0.058	2.033	1.660	−5.504	0.445	−4.539	0.620	−2.726	−4.905	2.383	−0.560
05-03-2020	AAR	**0.008**	**−0.011**	0.004	−0.002	**−0.006**	0.003	**0.015**	−0.006	**−0.010**	**−0.012**	0.005	0.000
	t-test	3.141	−3.033	0.975	−0.950	−3.316	0.330	3.534	−1.490	−4.608	−3.901	1.125	−0.057
	CAAR	−0.010	−0.009	**0.040**	**0.027**	**−0.025**	0.038	**−0.222**	0.013	0.003	−0.005	**0.024**	−0.016
	t-test	−1.168	−0.748	3.037	3.111	−3.984	1.547	−5.381	1.450	0.331	−0.385	2.208	−0.480
09-03-2020	AAR	**0.013**	**0.018**	−0.008	0.001	−0.009	−0.020	**−0.189**	0.007	**−0.058**	**−0.059**	−0.007	−0.009
	t-test	2.613	2.319	−1.202	0.167	−1.832	−1.150	−5.170	1.235	−10.302	−10.762	−0.644	−0.573
	CAAR	**0.035**	−0.027	**−0.057**	**0.023**	**−0.042**	−0.003	**−0.252**	**0.031**	**−0.158**	**−0.143**	−0.012	0.007
	t-test	2.769	−1.251	−2.817	2.032	−3.464	−0.946	−5.792	2.053	−11.279	−5.369	−0.503	0.141
12-03-2020	AAR	**0.018**	**−0.022**	**−0.047**	0.001	−0.011	**−0.030**	−0.012	0.002	**−0.084**	**−0.067**	−0.005	0.009
	t-test	3.601	−2.632	−6.119	0.227	−1.671	−5.925	−0.793	0.230	−15.447	−5.569	−0.523	0.443
	CAAR	0.020	**−0.128**	−0.030	−0.001	**−0.042**	0.039	**−0.321**	−0.006	**−0.156**	**−0.208**	−0.050	−0.004
	t-test	1.184	−5.068	−0.916	−0.052	−2.321	1.487	−5.624	−0.334	−8.274	−5.730	−1.564	−0.077
16-03-2020	AAR	**0.015**	**−0.027**	−0.007	−0.002	**−0.028**	0.012	−0.014	**0.025**	**−0.105**	**−0.151**	−0.013	0.008
	t-test	2.103	−2.921	−0.453	−0.185	−3.539	0.556	−1.127	2.932	−14.141	−12.795	−0.991	0.264
	CAAR	0.022	**−0.155**	−0.045	−0.025	**−0.041**	0.037	**−0.116**	**−0.045**	**−0.188**	**−0.263**	−0.032	−0.045
	t-test	1.351	−6.314	−1.585	−1.393	−2.018	1.543	−2.923	−1.870	−13.968	−8.418	−1.212	−0.784
18-03-2020	AAR	0.005	**−0.028**	**−0.026**	−0.002	−0.019	0.021	−0.011	−0.004	**−0.070**	**−0.101**	−0.009	−0.007
	t-test	0.657	−2.649	−1.838	−0.220	−1.573	1.548	−0.461	−0.374	−7.098	−6.258	−0.468	−0.289
	CAAR	**0.032**	**−0.099**	−0.018	**−0.070**	**−0.028**	0.010	0.002	**−0.053**	**−0.169**	**−0.250**	−0.033	**−0.086**
	t-test	2.334	−5.487	−0.904	−4.057	−1.936	0.330	0.072	−3.103	−12.457	−10.176	−1.118	−2.118
19-03-2020	AAR	0.006	**0.020**	−0.002	**−0.018**	0.013	−0.023	**0.049**	**−0.022**	−0.018	0.016	0.021	**−0.035**
	t-test	0.854	2.672	−0.182	−2.187	1.607	−0.722	2.836	−3.036	−1.494	1.121	1.231	−2.909
	CAAR	**0.034**	**−0.024**	**−0.030**	**−0.063**	−0.018	−0.026	0.040	−0.007	**−0.117**	**−0.244**	0.003	**−0.077**
	t-test	2.910	−1.763	−1.826	−4.640	−1.549	−0.678	1.323	−0.481	−8.046	−11.239	0.130	−2.084

Note: The values in bold shows the statistically significant values at the 5 percent level of significance.

Table 3
AAR and CAAR results of UK (±3).

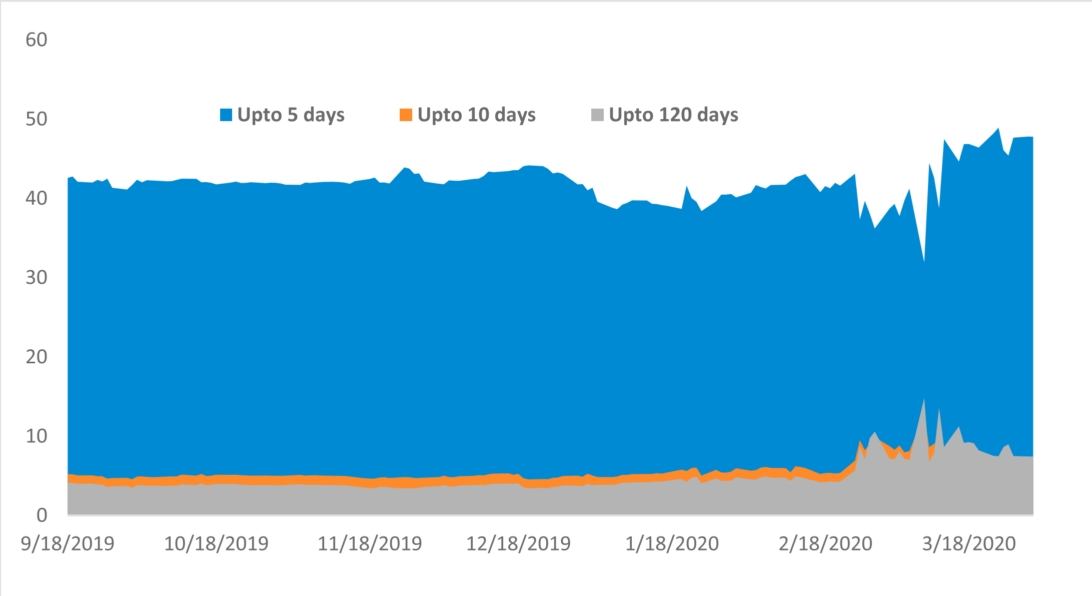
Stocks	Sectors	IT	ConsD	ConsS	Health	Fin.	Tele.	Energy	Indus.	Util.	Estate	Mate.	Misc
03-02-20	AAR	0.005	**0.008**	**−0.003**	**0.005**	**0.007**	−0.003	**−0.011**	−0.001	−0.003	0.002	**0.005**	**0.007**
	t-test	1.512	2.366	−1.849	2.137	5.332	−1.496	−3.959	−0.703	−1.211	0.914	2.599	2.576
	CAAR	−0.001	0.004	**−0.013**	0.008	0.023	**−0.020**	**−0.018**	−0.004	−0.006	−0.001	**0.084**	0.008
	t-test	−0.236	0.569	−1.948	0.918	2.425	−1.891	−2.617	−0.879	−0.841	−0.048	5.047	1.174
19-02-20	AAR	0.003	**0.004**	**0.006**	0.003	−0.002	0.007	**0.009**	−0.001	**0.006**	**0.005**	−0.003	0.004
	t-test	0.505	2.025	1.889	1.197	−0.994	1.442	2.261	−0.628	3.373	1.875	−0.286	1.560
	CAAR	0.003	**−0.028**	**−0.002**	0.005	−0.024	0.009	**−0.027**	−0.009	**0.026**	**0.010**	−0.006	0.000
	t-test	0.387	−3.108	−0.176	0.448	−4.461	0.841	−2.067	−1.425	2.035	2.609	−0.511	0.021
21-02-20	AAR	**0.004**	**−0.010**	0.001	**0.011**	**−0.006**	0.002	−0.006	0.002	**0.008**	−0.002	−0.008	0.000
	t-test	1.654	−4.026	0.367	2.874	−2.685	0.210	−1.023	0.983	4.169	−0.364	−1.578	−0.095
	CAAR	**0.028**	−0.001	0.003	0.000	**−0.010**	0.001	**−0.023**	0.015	−0.009	**−0.025**	**0.059**	**0.016**
	t-test	1.897	−0.051	0.236	0.015	−1.694	0.027	−1.924	1.512	−0.899	−3.538	3.156	1.954
24-02-20	AAR	0.004	**−0.021**	**−0.013**	**−0.015**	**−0.009**	**−0.007**	**−0.023**	**−0.007**	**−0.018**	**−0.008**	**0.006**	−0.002
	t-test	0.738	−3.688	−3.235	−1.682	−3.667	−2.219	−12.633	−2.327	−5.836	−2.779	1.894	−0.988
	CAAR	**0.039**	0.010	−0.008	−0.005	**−0.012**	−0.011	**−0.022**	**0.037**	**−0.019**	**−0.049**	**0.086**	**0.027**
	t-test	1.941	0.733	−0.473	−0.218	−1.793	−0.349	−2.685	2.813	−1.693	−4.457	2.935	3.211
27-02-20	AAR	**0.012**	0.006	−0.008	−0.004	−0.002	−0.003	−0.004	**0.018**	−0.001	**−0.021**	0.015	**0.006**
	t-test	1.786	1.288	−0.938	−0.341	−1.128	−0.363	−0.970	3.571	−0.098	−5.050	1.419	1.991
	CAAR	−0.012	−0.006	**−0.035**	−0.034	**−0.033**	**−0.054**	**−0.032**	−0.008	**−0.049**	**−0.068**	**0.103**	0.008
	t-test	−0.421	−0.405	−1.654	−1.012	−4.589	−3.962	−4.548	−0.586	−5.126	−4.939	3.568	1.005
04-03-20	AAR	**−0.030**	**−0.023**	**−0.009**	**−0.011**	**−0.025**	**−0.004**	**−0.020**	**−0.022**	**0.014**	**0.019**	**−0.035**	**−0.019**
	t-test	−4.505	−5.354	−1.868	−1.357	−7.306	−0.694	−3.280	−5.005	4.841	2.012	−4.569	−4.217
	CAAR	**−0.077**	−0.022	**−0.065**	**−0.063**	**−0.083**	**−0.121**	**−0.160**	**−0.059**	**−0.130**	**−0.080**	**0.104**	**−0.046**
	t-test	−3.318	−1.500	−3.595	−2.275	−7.327	−11.188	−8.390	−3.965	−12.806	−5.046	9.973	−3.695
05-03-20	AAR	0.003	**−0.013**	**0.008**	0.001	−0.001	**−0.010**	0.000	0.004	**−0.007**	−0.005	**0.014**	0.005
	t-test	0.420	−1.906	3.137	0.167	−0.491	−2.470	−0.035	0.980	−2.324	−0.619	6.526	1.142
	CAAR	**−0.094**	**−0.042**	**−0.088**	**−0.072**	**−0.098**	**−0.148**	**−0.169**	**−0.066**	**−0.149**	**−0.078**	**0.053**	**−0.068**
	t-test	−3.166	−2.903	−7.503	−2.483	−7.827	−8.329	−8.896	−4.232	−14.083	−5.129	1.834	−5.480
09-03-20	AAR	0.007	**0.016**	**−0.022**	**−0.015**	**−0.012**	**−0.043**	**−0.091**	0.006	**−0.071**	**−0.044**	**0.080**	−0.005
	t-test	0.627	1.847	−3.021	−1.691	−2.016	−4.501	−8.358	0.834	−15.264	−3.560	7.238	−0.510
	CAAR	−0.036	−0.010	**−0.100**	**−0.081**	**−0.083**	**−0.211**	**−0.263**	−0.040	**−0.299**	**−0.190**	**0.168**	**−0.054**
	t-test	−0.911	−0.510	−4.231	−2.290	−4.155	−8.699	−7.101	−1.477	−18.341	−5.494	8.915	−2.414
12-03-20	AAR	−0.009	−0.013	**−0.032**	−0.014	**−0.051**	**−0.084**	**−0.092**	−0.013	**−0.130**	**−0.103**	**0.072**	−0.012
	t-test	−0.451	−1.389	−2.680	−0.944	−5.845	−12.825	−4.150	−1.120	−16.250	−4.704	3.415	−1.188
	CAAR	**−0.056**	**−0.040**	**−0.062**	**−0.068**	**−0.104**	**−0.111**	**−0.213**	**−0.095**	**−0.293**	**−0.328**	**0.151**	**−0.054**
	t-test	−1.179	−1.558	−1.819	−2.288	−4.086	−4.552	−5.329	−2.876	−11.418	−5.767	6.441	−1.628
16-03-20	AAR	**0.038**	**0.021**	**0.037**	**0.046**	0.008	−0.015	0.010	0.012	−0.011	**−0.093**	**0.119**	**0.041**
	t-test	2.884	1.941	3.236	3.160	0.812	−1.289	0.572	1.106	−1.151	−4.701	6.088	2.887
	CAAR	0.007	−0.007	0.040	0.028	−0.003	0.050	−0.059	−0.048	**−0.163**	**−0.215**	**0.233**	0.010
	t-test	0.217	−0.243	1.309	0.742	−0.127	1.195	−1.191	−1.357	−5.494	−3.478	6.329	0.289
18-03-20	AAR	**0.021**	0.013	0.007	0.006	**0.036**	0.027	−0.006	−0.016	−0.017	**−0.045**	**0.120**	0.002
	t-test	1.558	1.299	0.648	0.357	3.263	1.104	−0.238	−1.025	−1.232	−1.739	2.512	0.118
	CAAR	**0.067**	**0.083**	**0.083**	0.013	**0.075**	**0.144**	**0.106**	0.020	−0.042	−0.047	**0.216**	**0.048**
	t-test	2.224	3.209	3.633	0.444	3.159	3.733	4.252	0.812	−1.472	−0.574	2.733	1.776
19-03-20	AAR	**0.024**	**0.019**	**0.028**	**0.035**	**0.023**	0.030	**0.035**	**0.038**	0.016	**0.091**	0.002	**0.021**
	t-test	2.038	1.742	2.127	4.542	2.727	1.263	1.689	3.965	1.331	3.880	0.082	2.299
	CAAR	**0.101**	**0.113**	**0.076**	**0.055**	**0.117**	**0.154**	**0.159**	**0.038**	0.001	0.021	**0.194**	**0.086**
	t-test	3.825	5.273	3.792	2.961	5.883	5.588	4.746	1.801	0.033	0.255	3.611	4.036

Note: The values in bold shows the statistically significant values at the 5 percent level of significance.

Table 4
AAR and CAAR results of Europe (±3).

Stocks	Sectors	IT	ConsS	ConsD	Health	Fin.	Tele.	Energy	Indus.	Util.	Estate	Mate.	Misc
03-02-20	AAR	**0.007**	0.002	0.003	−0.014	**0.004**	**0.012**	**−0.012**	**0.004**	0.006	−0.003	**−0.009**	**0.002**
	t-test	1.754	0.616	1.301	−1.394	2.352	1.746	−4.558	2.036	0.842	−1.387	−1.611	1.690
	CAAR	**−0.041**	0.004	**−0.010**	**−0.024**	0.005	−0.028	**−0.037**	0.001	−0.005	**−0.024**	0.013	**0.005**
	t-test	−2.007	0.597	−1.960	−2.219	1.210	−0.792	−1.917	0.118	−0.419	−2.357	1.035	2.115
19-02-20	AAR	0.001	0.003	**0.007**	0.001	**0.005**	0.002	0.003	−0.001	0.005	−0.002	**0.026**	**0.004**
	t-test	0.396	1.521	4.645	0.294	2.209	0.590	0.531	−0.231	0.921	−0.813	2.877	5.065
	CAAR	−0.006	−0.006	**0.016**	**0.016**	**0.016**	**0.034**	−0.015	0.008	**0.036**	**0.016**	**0.043**	**0.005**
	t-test	−0.561	−0.805	2.598	1.988	3.032	5.138	−0.781	1.146	3.262	2.825	1.944	1.764
21-02-20	AAR	**−0.007**	−0.002	**0.006**	0.004	0.001	0.002	**−0.013**	0.002	**0.007**	0.001	**0.023**	**−0.002**
	t-test	−2.058	−1.130	3.231	0.867	0.547	0.949	−2.688	0.571	1.932	0.329	2.352	−1.738
	CAAR	−0.015	−0.015	0.008	**0.019**	**0.029**	0.023	−0.001	**0.032**	**0.024**	0.001	**0.047**	**0.007**
	t-test	−1.492	−1.431	1.222	1.987	4.628	1.253	−0.046	3.251	2.086	0.112	3.277	2.028
24-02-20	AAR	−0.009	**−0.019**	**−0.005**	0.001	**0.005**	−0.001	**−0.013**	0.001	−0.004	0.002	**−0.014**	**−0.007**
	t-test	−1.520	−3.505	−2.098	0.153	2.037	−0.455	−1.894	0.399	−1.489	0.354	−2.738	−5.175
	CAAR	**−0.033**	**−0.034**	−0.005	0.013	**0.032**	−0.008	−0.008	**0.035**	**0.022**	−0.017	**0.033**	−0.004
	t-test	−2.271	−3.279	−0.624	0.865	4.367	−0.314	−0.252	2.639	1.560	−1.519	1.777	−0.869
27-02-20	AAR	**−0.022**	**−0.018**	**−0.011**	−0.001	0.001	**−0.013**	**−0.010**	−0.001	0.010	**−0.023**	−0.013	**−0.013**
	t-test	−2.595	−5.120	−3.462	−0.045	0.175	−1.948	−2.223	−0.197	1.338	−6.570	−1.436	−5.640
	CAAR	**−0.048**	**−0.072**	−0.013	−0.020	**0.016**	−0.040	−0.011	**0.020**	0.007	−0.018	−0.032	−0.007
	t-test	−3.851	−5.500	−1.202	−0.872	2.121	−1.167	−0.386	1.625	0.359	−1.259	−1.167	−1.371
04-03-20	AAR	**−0.020**	**−0.024**	−0.003	−0.001	**−0.022**	0.012	**−0.009**	**−0.020**	**0.013**	−0.009	−0.008	**−0.012**
	t-test	−6.483	−6.498	−1.164	−0.138	−8.812	0.882	−2.444	−4.726	2.620	−1.588	−1.288	−6.828
	CAAR	**−0.099**	**−0.057**	−0.001	−0.061	**−0.017**	**−0.041**	**−0.183**	0.001	−0.029	0.000	**−0.060**	**−0.032**
	t-test	−3.863	−3.969	−0.053	−1.448	−2.091	−1.952	−3.254	0.090	−0.873	−0.024	−2.330	−3.658
05-03-20	AAR	−0.006	**−0.018**	−0.003	0.004	−0.001	−0.003	**−0.011**	0.002	**0.005**	0.000	0.007	−0.006
	t-test	−0.600	−3.671	−0.743	0.378	−0.521	−0.326	−1.737	0.691	2.718	0.031	1.221	−1.272
	CAAR	**−0.099**	**−0.073**	**−0.024**	−0.056	**−0.027**	**−0.055**	**−0.215**	−0.015	**−0.055**	−0.003	−0.014	**−0.030**
	t-test	−3.863	−4.712	−1.604	−1.384	−3.390	−8.749	−3.087	−1.068	−2.136	−0.259	−0.707	−3.223
09-03-20	AAR	**−0.032**	**0.017**	0.008	−0.022	**0.015**	**−0.024**	**−0.123**	**0.028**	−0.021	**0.018**	**−0.033**	**−0.004**
	t-test	−3.036	2.368	0.944	−1.481	2.587	−1.653	−3.036	3.656	−0.991	2.055	−1.703	−1.067
	CAAR	**−0.098**	**−0.071**	−0.015	−0.064	**0.033**	**−0.052**	**−0.238**	**0.045**	**−0.112**	0.013	**−0.125**	**−0.033**
	t-test	−3.012	−2.940	−0.599	−1.165	2.235	−1.656	−2.416	1.663	−2.227	0.523	−2.279	−2.740
12-03-20	AAR	**−0.020**	**−0.042**	−0.004	−0.024	**0.014**	**−0.035**	−0.028	**0.015**	**−0.043**	−0.009	**−0.080**	−0.005
	t-test	−1.889	−3.054	−0.422	−1.238	1.999	−2.925	−0.637	1.562	−2.389	−0.727	−3.057	−1.013
	CAAR	**−0.160**	**−0.306**	**−0.078**	**−0.102**	0.027	−0.031	**−0.204**	**−0.009**	−0.043	**−0.078**	−0.057	**−0.090**
	t-test	−3.874	−5.151	−2.113	−2.105	1.038	−0.394	−2.987	−0.178	−0.587	−2.132	−0.608	−5.345
16-03-20	AAR	−0.012	**−0.084**	−0.001	0.013	**0.036**	0.009	0.038	**0.032**	0.028	−0.025	0.030	−0.005
	t-test	−0.752	−3.413	−0.044	0.765	4.428	0.207	1.374	1.988	1.460	−1.577	0.808	−0.680
	CAAR	**−0.180**	**−0.292**	**−0.096**	**−0.057**	0.009	0.075	−0.063	−0.027	0.019	**−0.141**	−0.075	**−0.142**
	t-test	−3.632	−4.893	−2.012	−1.954	0.285	0.786	−0.999	−0.600	0.343	−3.409	−0.843	−7.888
18-03-20	AAR	**−0.052**	0.010	−0.014	0.001	0.014	0.052	−0.050	0.004	0.023	−0.018	−0.021	**−0.043**
	t-test	−2.459	0.283	−0.531	0.087	1.054	1.497	−1.505	0.237	1.040	−0.753	−0.785	−5.475
	CAAR	**−0.142**	**−0.169**	**−0.085**	−0.034	−0.020	**0.111**	0.064	−0.032	−0.031	**−0.130**	**0.084**	**−0.109**
	t-test	−3.117	−3.819	−2.257	−1.005	−0.886	1.881	1.115	−1.014	−0.851	−4.068	1.607	−7.658
19-03-20	AAR	−0.004	0.004	−0.021	0.004	**−0.027**	0.011	0.023	−0.010	−0.026	**−0.038**	**−0.036**	**−0.025**
	t-test	−0.178	0.240	−1.251	0.151	−2.638	0.408	0.636	−0.337	−1.183	−2.468	−2.943	−4.741
	CAAR	**−0.093**	**−0.070**	**−0.076**	0.029	−0.001	**0.125**	**0.189**	−0.024	−0.039	**−0.107**	**0.163**	**−0.056**
	t-test	−2.261	−2.022	−2.129	0.996	−0.073	2.596	2.575	−0.901	−1.318	−3.135	5.542	−4.538

Note: The values in bold shows the statistically significant values at the 5 percent level of significance.



Notes: This figure displays frequency connectedness of USA, UK and the Europe stock markets using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.

Fig. 2. Frequency connectedness of USA, UK, and European stock markets.

Notes: This figure displays frequency connectedness of USA, UK and the Europe stock markets using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.

identify the multiple structural breaks at unknown dates. Specifically, the basic premise of the BP test is to identify the unknown structural break date based on sup $F_T(k, n)$ test, which tests the null hypothesis of no structural break ($n = 0$) against the alternative of a structural break ($n = k$). The null hypothesis remains the same for the double maximum and sequential test criteria, which also add a methodological dimension to structural breaks.

We then adopt the nonlinear econometric technique to confirm whether the dates identified by the BP test are appropriate or not. Considering the daily data, we use the Markov Switching (MS-DR (dynamic regression)) of Doornik (2013). We specify the MS-DR model with switching intercept (means) and the variance:

$$r_t = \alpha_i(S_t)r_{t-i} + \mu(S_t) + \varepsilon_t \tag{1}$$

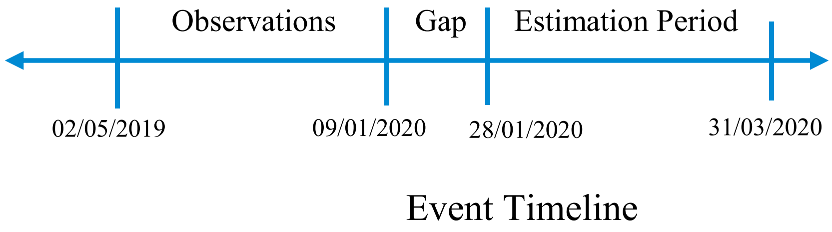
$$\varepsilon_t \sim iid\left[0, \sigma^2(S_t)\right], S_t = 1, 2$$

where the market return r_t is generated as an autoregression of order k with regime-switching in intercept (mean) μ and variance (σ^2). α_i is the model parameter and $\varepsilon_t$is a residual term. $S_t$represents the regimes which take values 0 and 1, respectively, for regime 1 (bearish) and regime 2 (bullish). Considering that the first phase of Coronavirus was limited to China, Italy and then to the UK and US during February and March 2020, we apply the structural break tests on the growth of total deaths due to Coronavirus and broad indices of four countries, which include China, Italy, the US, and the UK.

In the second step, we map the unknown dates with credible news reports from the news agencies such as the New York Times, Bloomberg, and The Guardian. Lastly, we adopt the Event Study Methodology (ESM) to investigate the event-specific impact on firms in consideration. Staikouras (2009) and Kim et al. (2020) also use ESM for their analysis. We use the ESM to measure the Abnormal Returns (AR) and Cumulative Abnormal Returns (CAR) to capture the firm-specific event-related effects, and then to measure the *Average Abnormal Returns* (AAR) and *Cumulative Average Abnormal Returns* (CAAR) to perform an industry-level analysis. The market model is as follows:

$$ExR_{it} = \alpha_{it} + \beta\left(R_{mt} - R_{ft}\right) + \gamma SMB_t + \delta HML_t + \varepsilon_{it} \tag{2}$$

where ExR_{it} is the excess return of stock i at time t, R_{mt} is market index return, R_{ft} is the risk-free return at time t, SMB_t is the size premium at time t, HML_t is the value premium at time t and $\varepsilon_{i,t}$ is the error term. α, β, γ, and $\delta$are estimated parameters. We have chosen the evaluation period to be of 175 trading days with a 12-trading day gap from the observation period.



Utilising the estimated market model, we calculate the AR and the CAR values as follows:

$$AR_{it} = R_{it} - E(R_{it}) \tag{3}$$

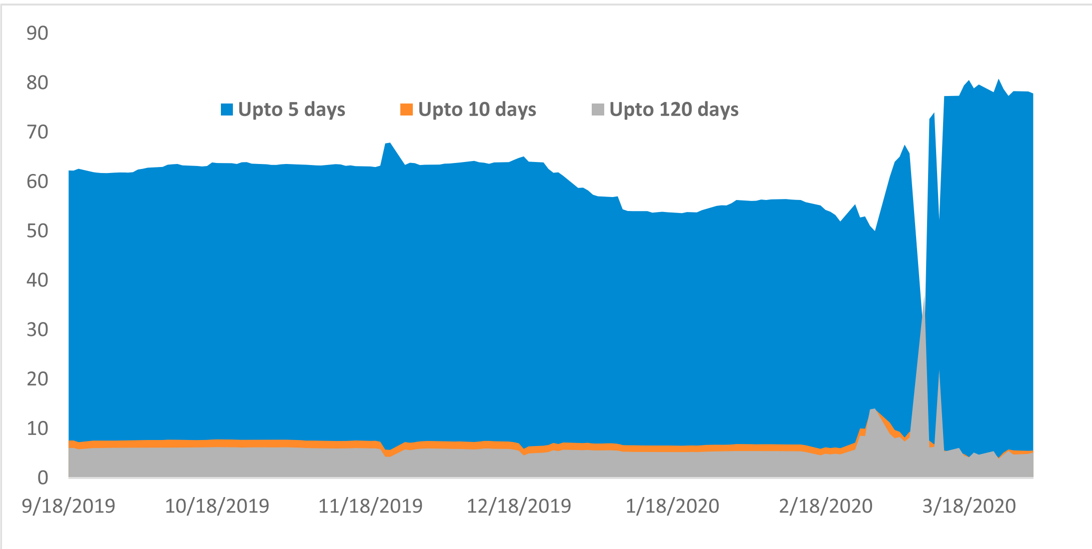
$$CAR_i = \sum_{t=t_0}^{t_1} AR_{it} \tag{4}$$

where, R_{it} is the actual return of firm i at time t, $E(R_{it})$is the estimated return using the computed market model. The CAR_i is then computed by taking the sum of theARs over the chosen event window. To better isolate the event-specific abnormalities, short event windows of [-1, +1] and [-3, +3] were considered. Using a sector-wise classification of Thomson DataStream, the AAR and CAAR values were then calculated as below.

$$AR_{it} = \frac{1}{n}\sum_{i=1}^{n} AR_{it} \tag{5}$$

$$CAAR_{it} = \frac{1}{n}\sum_{i=1}^{n} CAR(t_1, t_2) \tag{6}$$

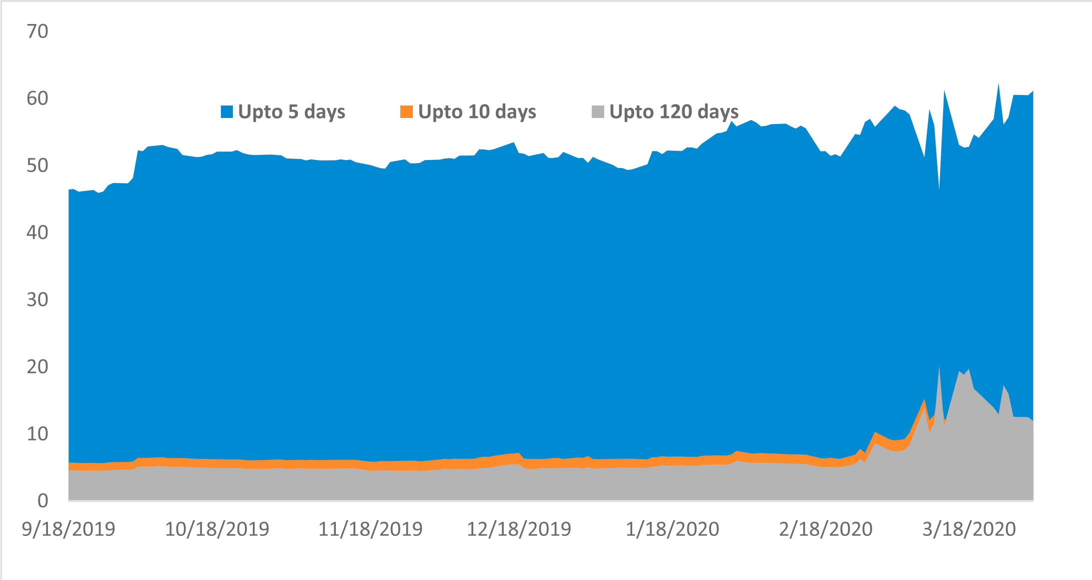
Finally, to establish the significance of the evaluated AR, CAR, AAR and CAAR values, we conducted t-tests as follows: $t_{AR_{i,t}} = AR_{i,t}/S_{AR,i}$; where$S_{AR,i}$ is the standard deviation of the AR values calculated in the estimation window. $t_{CAR_{i,t}} = CAR_{i,t}/S_{CAR,i}$, where,



Notes: This figure displays frequency connectedness of US stock markets at intersectoral level using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.

Fig. 3. Frequency connectedness of US stock markets.

Notes: This figure displays frequency connectedness of US stock markets at intersectoral level using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.



Notes: This figure displays frequency connectedness of the UK stock markets at intersectoral level using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.

Fig. 4. Frequency connectedness of UK stock markets.
Notes: This figure displays frequency connectedness of the UK stock markets at intersectoral level using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.

$S_{CAR,i} = L \times S_{CAR,i}$, L is the length of the event window. For AAR, $t_{AAR_{i,t}} = \sqrt{N} \times AAR_{i,t}/S_{AAR_t}$, where, S_{AAR_t} is the standard deviation across firms at time t. $S_{AAR_t} = 1/N - 1 \times \sum_{i=1}^{N}(AR_{i,t} - AAR_t)^2$. The null hypothesis is $AAR = 0$. $t_{CAAR_{i,t}} = \sqrt{N} \times CAAR_{i,t}/S_{CAAR_t}$, where S_{CAAR_t} is the standard deviation of CAR across the sample. It is defined as the same as S_{AAR_t}.

3. Results and discussion

Table 1 shows the event dates identified by the multiple structural break test. The BP test though linear by specification, identifies the major turning points during coronavirus outbreak. For instance, from the stock market perspective, the model determines the black swan events observed during the March 9–12. According to WEF (2020), The U.S. Securities and Exchange Commission (SEC) used circuit breakers to the S&P 500 on March 9, 12, 16, and 18. In February, the BP test captures events related to coronavirus outbreak in South Korea and Italy appropriately. The dates are further confirmed by the smoothed probabilities of the MS-DR model plotted against the global growth of coronavirus cases and deaths (see Fig. 1, Panels A & B). The major events identified by the BP and MS-DR tests exhibit some contrariness with Al-Awadhi et al. (2020) and Corbet, Larkin, and Lucey (2020), and it could be due to difference in methodology. The US, UK, and European markets exhibit bearish trends during February (last week) and March (first week). According to CNBC (2020), in the last week of February, the Dow-Jones Index fell by 3500 points. S&P 500 Composite Index also fell by more than 10%. The UK stock market also experienced the same as it also fell by more than 3%. In the last week of February, the epidemic fears led to a fall of more than 10% (Wearden, 2020).

Tables (2–4) show the results of AAR and CAAR of the US, UK and European sectors. For [-3, +3] event window, we observe that during the first and second weeks of February, the impact of the coronavirus epidemic is staggered. In the US, the consumer discretionary, consumer staples, financials, energy, utilities, and real estate stocks exhibiting negative values than the rest of the sectors, indicating the significant impact of Coronavirus related events on these sectors' returns. For the US economy, Sharif et al. (2020) also report the strong impact of COVID-19 pandemic on the stock market. The sectoral results are in line with Haroon and Rizvi (2020) who employ sectoral indices for the US and find that COVID-19 related news had a significant impact on the Basic Materials, Consumer Goods, Industrial Goods, Banks, Technology, Hotels, Media, Delivery Services and Insurance, Transportation, Automobiles & Components, Energy and Travel & Leisure industries. It is also consistent with Goodell and Huynh (2020) who identify positive abnormal returns for the US medical and pharmaceuticals sectors and negative abnormal 'eturns for restaurants and hotels and motels.

From the investors' perspective, we can say that the US stock market had an excellent opportunity for portfolio rebalancing or buying

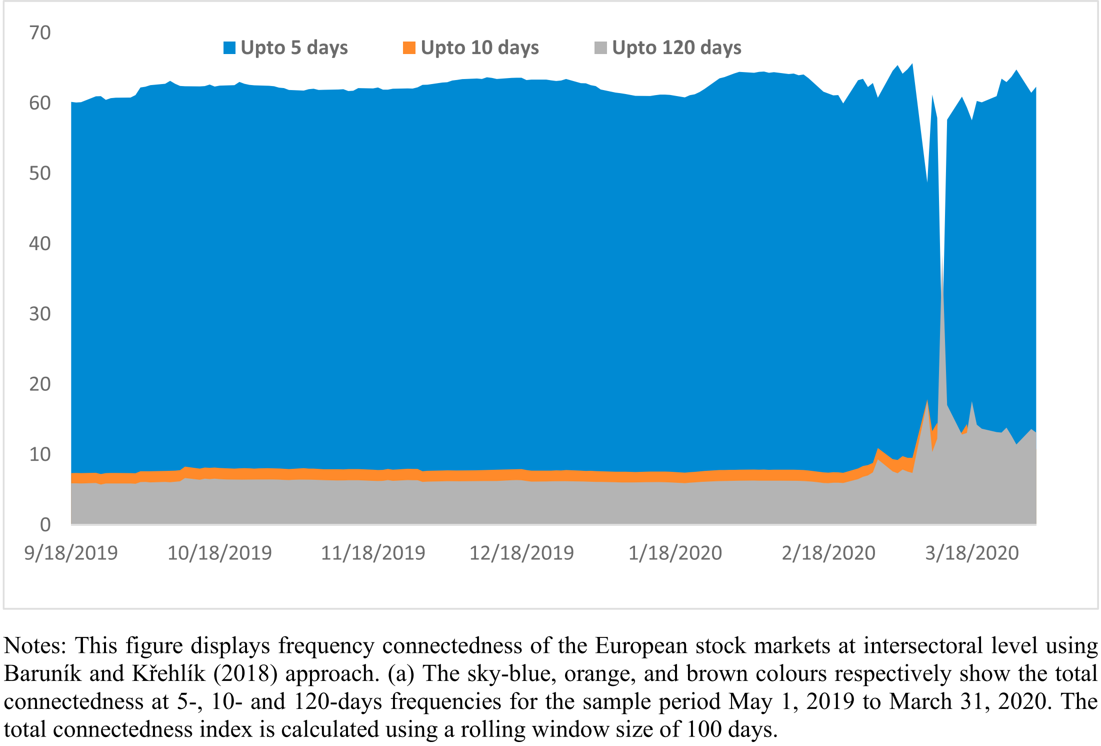


Fig. 5. Frequency connectedness of European stock markets.
Notes: This figure displays frequency connectedness of the European stock markets at intersectoral level using Baruník and Křehlík (2018) approach. (a) The sky-blue, orange, and brown colours respectively show the total connectedness at 5-, 10- and 120-days frequencies for the sample period May 1, 2019 to March 31, 2020. The total connectedness index is calculated using a rolling window size of 100 days.

strategies until February 27. Beyond that, the market seems to be completely trapped by the Coronavirus outbreak. For the UK, the impact of pandemic was observed from the first week of March as most sectors have AAR and CAAR values negative and statistically significant. Except for healthcare, financials, and telecommunication sectors, we see all the sectors highly sensitive to the coronavirus outbreak. For Europe, unlike US sectors, we find symmetry in the signs of the AAR and CAAR values, which again confirm the impact of coronavirus outbreak. We also observe that consumer durables, consumer staples, financials, energy, utilities, and real estate are the worst impacted sectors. However, post-March 16, we see a reverse trend as some sectors show positive and significant AAR and CAAR values with some sectors such as IT, consumer durables, consumer staples, financials, and energy exhibiting positive and significant values for AAR and CAAR. These results remain the same for the USA, UK, and Europe even at smaller estimation window [-1, +1] (See Online Appendix Tables A1-A4).

4. Connectedness analysis

In order to confirm the above findings, we also confirm it by analysing the strength (degree and speed) of connectedness to COVID-19 shocks at frequent intervals using the frequency connectedness approach of Barunik and Krehlik (2018, hereafter BK).[3] The rationale of conducting this analysis is to examine the reaction of the USA, UK, and Europe at different frequencies and reveal the commonalities. In this regard, the BK (2018) seems an appropriate analysis as it allows to examine the connectedness at different frequencies (time intervals), usually denoted as short- and long-term. The BK (2018) derives the frequency response function using Fourier transform. The generalized causation spectrum over $\omega = \in (-\pi, \pi)$, is expressed as:

$$(f(\omega))_{j,k} \equiv \frac{\sigma_{kk}^{-1}\left|(\Psi(e^{-iw})\Sigma)_{j,k}\right|^2}{\left(\Psi(e^{-iw})\Sigma\Psi'(e^{+iw})\right)_{j,j}} \tag{7}$$

where is $\Psi(e^{-iw})$ represents the Fourier transform of the impulse response Ψ. It is essential to document that the fraction of the spectrum

[3] We are thankful to Anonymous referees for excellent suggestion. The incorporation of suggestion has improved the quality of our paper.

of the $j-th$ variable at frequency ω as caused by shocks in the $k-th$ variable is represented by $(f(\omega))_{j,k}$, and it is construed as the within-frequency causation measure. In line with BK (2018), the generalized FEVD (GFEVD) on certain frequency band d is obtained thus:

$$(\theta_d)_{j,k} = \frac{1}{2\pi}\int \Gamma_j(\omega)(f(\omega))_{j,k}d\omega \tag{8}$$

where the function for weighting is represented by $\Gamma_j(\omega)$. Considering the spectral representation of the GFEVD, the frequency-based connectedness on the frequency band d is defined as thus:

$$C_d^F = 100\left[\frac{\sum_{j\neq k}\left(\tilde{\theta}_d\right)_{j,k}}{\sum\left(\tilde{\theta}_\infty\right)_{j,k}} - \frac{Tr\left\{\tilde{\theta}_d\right\}}{\sum\left(\tilde{\theta}_\infty\right)_{j,k}}\right] \tag{9}$$

The total connectedness is then calculated as:

$$C_d^W = 100\left[1 - \frac{Tr\left\{\tilde{\theta}_d\right\}}{\sum\left(\tilde{\theta}_d\right)_{j,k}}\right] \tag{10}$$

We report the plots of frequency connectedness at three frequencies: (a) up to 5 days, (b) up to 10 days, and (c) up to 120 days during the sample period. We analyse these markets in two stages. At the inter-market level, we want to know the extent of connectedness at varying frequencies and observe the market reaction during the COVID-19 outbreak. Fig. 2 shows the inter-market connectedness of sample markets. It appears that the impact of coronavirus shock is visible during the first and second weeks of March 2020, and the stock market connectedness is higher at the shortest frequency (up to 5 days) compared to ‘0 and 120 days. This result implies that the USA, UK, and Europe's stock markets had similar reactions to the Coronavirus outbreak though the severeness may differ. The stock market reactions are visible on February 27, March’9 and March 12. Second, we also examine the sample stock markets' inter-sector reactions using 5, 10, and 120 days frequencies (Figs. 3–5). It appears that the 5-days frequency exhibit higher connectedness than the 10-days and 120-days, indicating the short-term reactions of Coronavirus on these markets.[4] Specifically, the US sectoral connectedness exhibits major dips on February 27 and March 9 and 12, whereas European stock markets saw major decline on March 9 and 12. The intersectoral connectedness of UK market exhibit moderate reactions on March 9 and 12. Overall, it is evident that the Corovairus outbreak's impact is severe for the USA, and Europe and UK stock market exhibits some resilience. Hence, the frequency connectedness analysis confirms the above findings and concludes the presence of black swan events. We do find some differences in the speed and degree of reactions to COVID-19 shocks at the inter-sectoral. For instance, USA and Europe exhibit severe impact as compared to the UK market.

5. Conclusion

All else equal, until March 31, 2020, we find that the investors had limited investment opportunities except for a few sectors in the US, UK, and Europe due to black swan events. February 27, March 9, and March 12 are the events to be analysed from the market microstructure perspective. The frequency connectedness approach results also confirm the common reactions of inter-market and inter-sectoral connectedness of the sample markets, analysed at 5, 10, and 120 days. Specifically, we find some stocks in consumer staples, healthcare, telecommunications, utilities, and financials were the attention-seekers. In addition, different sectors in our sample countries had different reactions to the outbreak. Our results have significant implications for investors who diversify in different industries and policymakers who closely observe the developments in the different sectors of the economy. For example, policymakers may provide support packages for the worst impacted sectors, and investors may undertake portfolio rebalancing or design buying strategies accordingly.

CRediT authorship contribution statement

Wasim Ahmad: Conceptualization, Investigation, Writing – original draft, Data curation, Methodology, Formal analysis. **Ali M. Kutan:** Supervision, Visualization, Investigation, Writing – review & editing. **Smarth Gupta:** Data curation and analysis, and review and editing.

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[4] We also report the descriptive statistics of stock market connectedness at different frequencies (5, 10, and 120 days). Please refer to Table A4 (Online Appendix) for details. It appears that the stock market connectedness at 5-days frequency exhibits the strongest connectedness for all the countries, suggesting that the short-term impacts are much stronger than the long-term impacts even regarding the extent of connectedness.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iref.2021.04.007.

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