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ORIGINAL ARTICLE

The day after tomorrow: financial repercussions of COVID-19 on systemic risk

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Abstract

In this paper, we study the financial repercussions of COVID-19 and the effect of anti-epidemic measures on financial markets. By using a composite dataset containing stock market indices of 10 countries characterized by heterogeneous levels of contagion, the daily COVID-19 cases and the 108 more restrictive measures implemented to limit the virus from 31/12/2019 to 13/03/2020, we examine the emergence of financial systemic risk, its speed of propagation and the effectiveness of the policies implemented to curb it. On the one hand, the spread of contagion and its transmission on financial markets are investigated via a lagged cross-correlation analysis. Our results show the emergence of systemic risk characterized by a high speed of diffusion. On the other hand, an augmented AR(1)-EGARCH(1,1) model is applied to examine the impact of anti-COVID-19 "policies on financial markets. We show that, regardless of the level of contagion, the restrictive measures are not able to contain the virus-induced investors panic in the first months of the epidemic.

Keywords COVID-19 · Policy measures · Stock markets

JEL Classification G01 · G14 · G15 · G18

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1 Introduction

"Epidemics and financial crises share certain general features, such as the potential to spread globally in an increasingly interconnected world, characterized by rapid mobility of people, commodities, information and capital. Disease outbreaks may also induce market turbulence, necessitating catastrophic risk management." Peckham (2013a).

The speed of globalization in spreading catastrophic events was suspected even in 1889—during the "Asiatic Flu"—when, in approximately two months, the virus propagated from Russia to America due to "modern transport infrastructure"[1]. More than a century later—having a variety of data available—we can offer a deeper explanation of the dynamics of the contagion and its repercussion in the economic context.

Generally speaking, it is well known that the spread of epidemics has strong repercussions on markets and exacerbates financial contagion (Peckham 2013b) by generating a significant increase in prices co-movement due to systemic interconnection (see Pericoli and Sbracia 2003 and Bargigli and Tedeschi 2014, for an extensive review).[2] A branch of economic literature closely linked with complexity science identifies in the self-reinforcing interaction among market participants the channel to propagate/reduce financial frictions which translate into booms followed by busts (see Grilli et al. 2020 for references on this topic). Typically, news, expectations and uncertainty about the future state of the world generate coordination phenomena or herding effects in traders' actions which affect stock market returns (see Wurgler and Baker 2007 and Chen et al. 2013). Different studies dealing with the emergence of financial contagion due to viruses spread, in fact, have found evidence of investors' overreaction, due to the arrival of news on virus outbreaks, able to destabilize financial markets (see Donadelli et al. 2016). In a similar vein, it has been shown that information on the health system resilience and the countries socio-economic stability has had a significant impact on stock markets both in the case of SARS in Asia and Ebola in Africa (Hanna and Huang 2004; Giudice and Paltrinieri 2017).

Given their historic recurrence [3], pandemics can no longer be considered "black swan event" (Taleb 2007), highlighting the importance of the related risk management. Surely, they stress the governments' preparedness to deal with (un)expected and potentially disastrous shocks.

The recent vicissitudes due to the COVID-19 attack have reopened the debate on issues related to the systemic interconnectivity and on the measures to contain systemic risk. A rich and recent literature encouraged by the need to face the pandemic emergency has studied the virus socio-economic impact. Without wishing to be exhaustive, let us mention some papers dealing with the dynamics of the COVID-19 diffusion (Alos et al. 2020; Kraemer et al. 2020; Buscema et al. 2020; Lee et al.

[1] https://en.wikipedia.org/wiki/1889_1890_pandemic

[2] Generally speaking, the collapse of the stock market is crucial in destabilizing the whole economic and financial system (Riccetti et al. 2016). This aspect exalts the relevance of the problem.

[3] https://www.newyorker.com/news/daily-comment/the-pandemic-isnt-a-black-swan-but-a-portent-of-a-more-fragile-global-system

2020)[4], its impact on financial markets (Albulescu 2020; Ramelli and Wagner 2020; Conlon and McGee 2020; Corbet et al. 2020; Akhtaruzzaman et al. 2021; Caferra and Vidal-Tomás 2021) and the measures/policies implemented to reduce its economic/financial spread (Gormsen and Koijen 2020; McKibbin and Fernando 2020; Kingsly and Henri 2020; Baldwin and di Mauro 2020; Collard et al. 2020). In this paper, we intend to contribute to the last two lines of research. Specifically, we ask the following questions: was there a correlation between the COVID-19 spread and the financial markets collapse? How have financial markets responded to the measures implemented to curb the contagion? In order to answer these points we use several daily time series concerning closing values of 10 stock market indices, daily numbers of COVID-19 infections and data on the restrictive measures implemented to control the contagion. The analysis, running from 31/12/2019 to 13/03/2020, is conduced on a heterogenous sample of countries which, during the investigated time period, show different levels of infections. Specifically, we collect data from Italy, Spain, Germany, France, China, South Korea where there is a medium/high number of infected people, and from Israel, the USA, Russia and the UK, where few infections are registered. From a methodological point of view two approaches are adopted. On the one hand, to study the synchronization between market indices dynamics and number of infections, we utilize the cross-correlation function. Although this technique is simple, the results are clear, highlighting the fast migration of the virus and its economic consequences. In line with other studies (see, for instance, Ramelli and Wagner 2020), we show that the pandemic quickly turned into a financial crisis. Interestingly enough, this is true not only for the highly infected areas but also for those COVID-19 free. Moreover, the lagged cross-correlation analysis allows us to grasp the speed of the infection transmission. We show that the virus just needs 15 days to spread from East to West. Furthermore, once in Europe, the speed of diffusion exponentially increases and the financial collapse happens the day after the pandemic arrive in Italy. On the other hand, to analyze how financial markets respond to the anti-COVID-19 measures, we implement an augmented AR(1)-EGARCH(1,1) model. This approach, based on the Efficient Market Hypothesis, is traditionally used to capture the impact of exogenous shocks on financial returns (Karafiath 1988; Hansen and Lunde 2005; Malik 2011; Vidal-Tomás and Ibañez 2018; Zaremba et al. 2020). It assumes that new public information is incorporated in prices motions and, consequently, these reflect the traders reaction (such as pessimism and optimism waves) following the announcement. As the reader can appreciate later on, our results show a general unstoppable pessimism that is not reversed by anti-COVID measures in the most affected countries' stock markets. On the contrary, the stock exchanges of less infected countries remain indifferent to the measures, showing not to believe in their preventive effect.

One year later, in 2021, different studies employed a retrospective analysis of the mitigatory effect of implemented policy measures (see Haug et al. 2020). As stated

[4] An interesting approach using network theory to describe viruses spread is proposed (Brockmann and Helbing 2013).

by the authors, drastic measures have been the "nuclear option" for COVID-19: on the one hand, the short-term negative expectations have been reversed by the long run effectiveness of restrictions in containing the contagion; on the other hand, different collateral consequences might have took place on the socio-economic system. Here, we prove evidence of the investors behavior in the early stage of the unstoppable virus outbreak, detecting if, even in the financial context, their short-term expectations have considered more the collateral effects (i.e., the sub-basement of the economic system) at the expense of the future benefits (i.e., the complete recovery of the system).

The rest of the paper is organized as follows. In Section 2, we describe the dataset. In Sections 2.1 and 2.2, we present the results on the spread of the virus and on the effectiveness of the measures applied to curb it. Specifically, we show the correlation analysis and the augmented AR(1)-EGARCH(1,1) model. Finally, Section 3 concludes.

2 Data and descriptive analysis

The goal of this paper is to analyze the financial contagion generated by the COVID-19 spread and the effectiveness of the measures implemented to mitigate it. In this regard, three types of sources are used: (i) the daily closing values of 10 stock market indices characterizing countries with different levels of contagion. These indices, downloadable from Thomson Reuters Eikon, are: the MIB (Italy), the Ibex35 (Spain), the DAX30 (Germany), the CAC40 (France), the FTSE100 (UK), the S&P500 (USA), the TA125 (Israel), the MOEX (Russia), the SHANGAI Composite (China) and the KOSPI (South Korea). All the selected countries, with the exception of Israel, the USA, Russia and the UK, where few infections are registered, report a medium/high number of infected people in the selected time window. The heterogeneity of the sample, and particularly the four counterfactual countries, allow us to understand if the financial contagion spreads regardless of the disease real attack, and the credibility of the preventive policies to contain it. (ii) The daily COVID-19 cases downloadable from the European Centre for Disease Prevention and Control database[5]. (iii) A dataset containing the 108 more restrictive measures implemented to control the contagion. These country-specific measures include travel restrictions, policy measures and National emergencies Acts. The dataset is built by merging the detailed time-line provided by Wikipedia with the GardaWorld.com website.[6]

The analyzed time window runs from 31/12/2019 to 13/03/2020. The start and end dates correspond, respectively, to the day on which China officially announces the existence of the outbreak COVID-19 and the day after the characterization of this disease as "pandemic" by the World Health Organization. The end data (i.e., March 13) is set to capture only the "real" impact of the anti-COVID measures on financial markets and not the panic generated by the World Health Organization announcement.

[5]Data on the number of infected persons per day are available every week: https://www.ecdc.europa.eu/en/publications-data/download-todays-data-geographic-distribution-covid-19-cases-worldwide.

[6]The dataset is included in Appendix 1.

The time series of the stock index prices and returns are shown in Fig. (1). As expected, the Chinese financial market is the first to suffer from the impact of COVID-19. However, due to the closure of the Chinese stock market from 23/01/2020 to 03/02/2020 for the Lunar New Year holiday, the drop in prices occurs after the onset of the disease (see point "a" in the figure). The shock wave takes about 15 days to hit the other markets and is particularly aggressive in Italy. In Fig. 2, we report the number of new daily cases of infections (blue bar) and the date when the measures to contain the contagion are implemented (dashed line).[7] As the reader can observe, most of the countries begin to apply massively anti-contagion measures only once the infection starts in their own territory. Two interesting exceptions are Russia and Israel where strong prevention measures are observed. On the other hand, the behavior of the UK is unusual. Here we observe some preventive measures, related to "flight routes suspensions," but any intensification of these measures when the infection appears on the national territory.

2.1 The spread of financial contagion

In this session, we study the spread of contagion and its transmission on financial markets. Considering China (Italy) as the worldwide (Western) trigger point, we analyze (i) the cross-correlation between the growth rate of the number of new daily infections in China (Italy) and the lagged growth rate of the number of infection in the other countries and (ii) the corresponding cross-correlation between the returns of stock market indices (see Chatfield 1994 and Shen and Zheng 2009, for a similar approach). With this methodology, we do not aim at studying the causality effect between COVID-19 and market movements, but we would infer, considering each pairwise couple of countries i) the cross-country propagation time of both virus and financial shock, and ii) the synchronization of the two mentioned events, observing the alignment between the peaks of correlation of COVID-19 cases and market indexes. Results are reported in Fig. 3. As the reader can observe, the correlations show similarities in the spread of the contagious and in the relation between the indices. Before the onset of the infection (i.e., up to lag 0), all returns time series were already slightly correlated. This fact reflects the well-known synchronization in the financial markets also known as globalization (see Saunders and Cornett 2014 and Alfarano et al. 2019). As we can see, the COVID-19 outbreak in China generates a "desynchronization" between the return series due to the Chinese market collapse. Obviously, also the correlation between the numbers of infections is negative in the first positive-lags—China, in fact, is the first country to be affected by the disease.

[7] It is worth mentioning that, later in time, some doubts arose on the accuracy of both (i) early-stage daily cases data, since different (criticized) countries-specific detection methods were adopted (Iacobucci 2020), and (ii) the detection of number of deaths, since different problems arose in properly identifying the causality between COVID-19 and deaths on the light of other potential omitted variables/diseases (Brown 2020; Woolf et al. 2020). In this case, we do not enter the merit of the calculation method employed, and we limit ourselves in considering the high trust level that readers can have on the authoritative data source announcing virus contagion. We opt for daily cases as the raw proxy of virus diffusion and, consequently, as the early-warning indicator of potential stress of the health (and then economic) system. Furthermore, we cannot use the number of deaths since Russia and Israel did not record any case in the selected period.

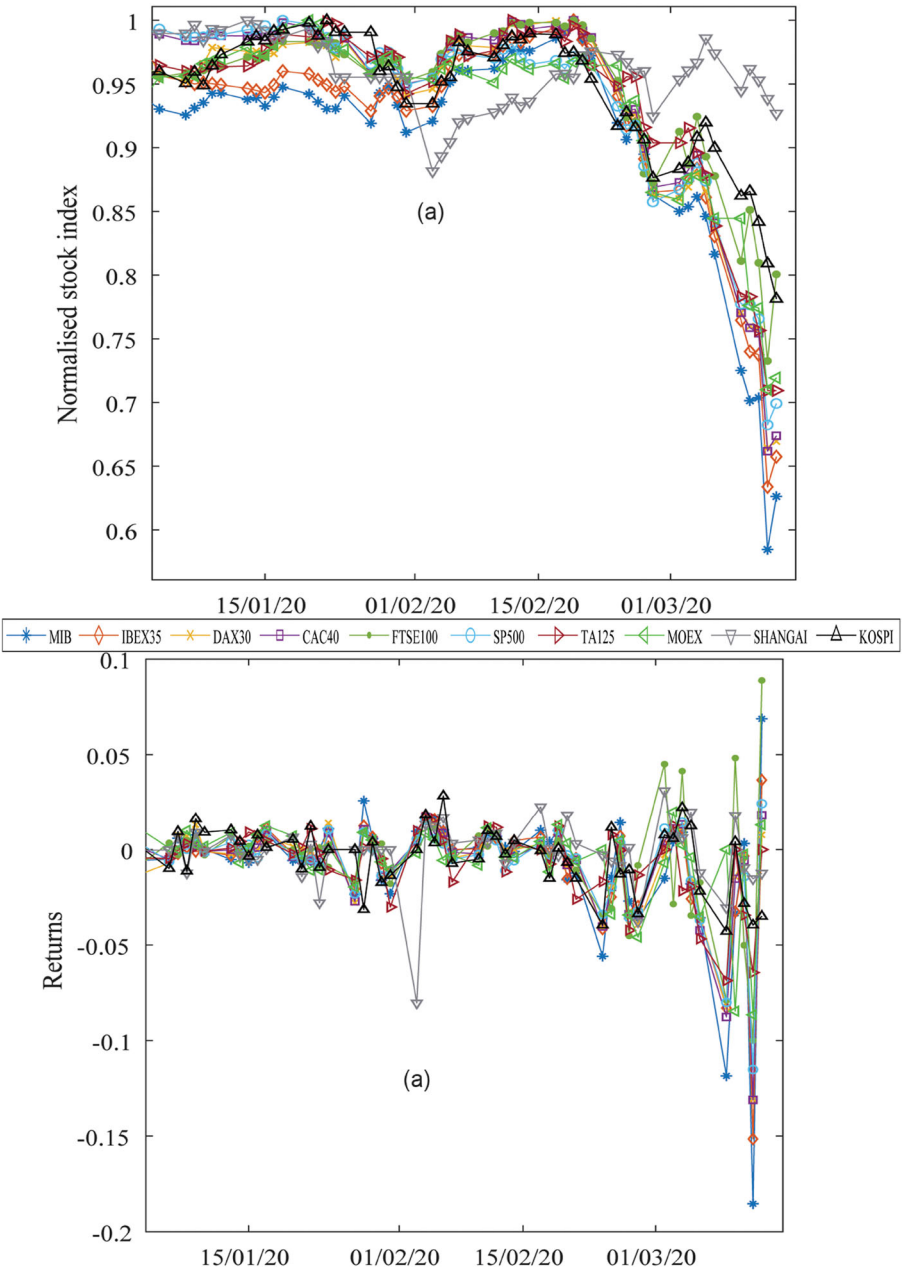

Fig. 1 Normalized stock index prices and returns from 31/12/2019 to 13/03/2020. **Indexes are normalized using their maximum value**

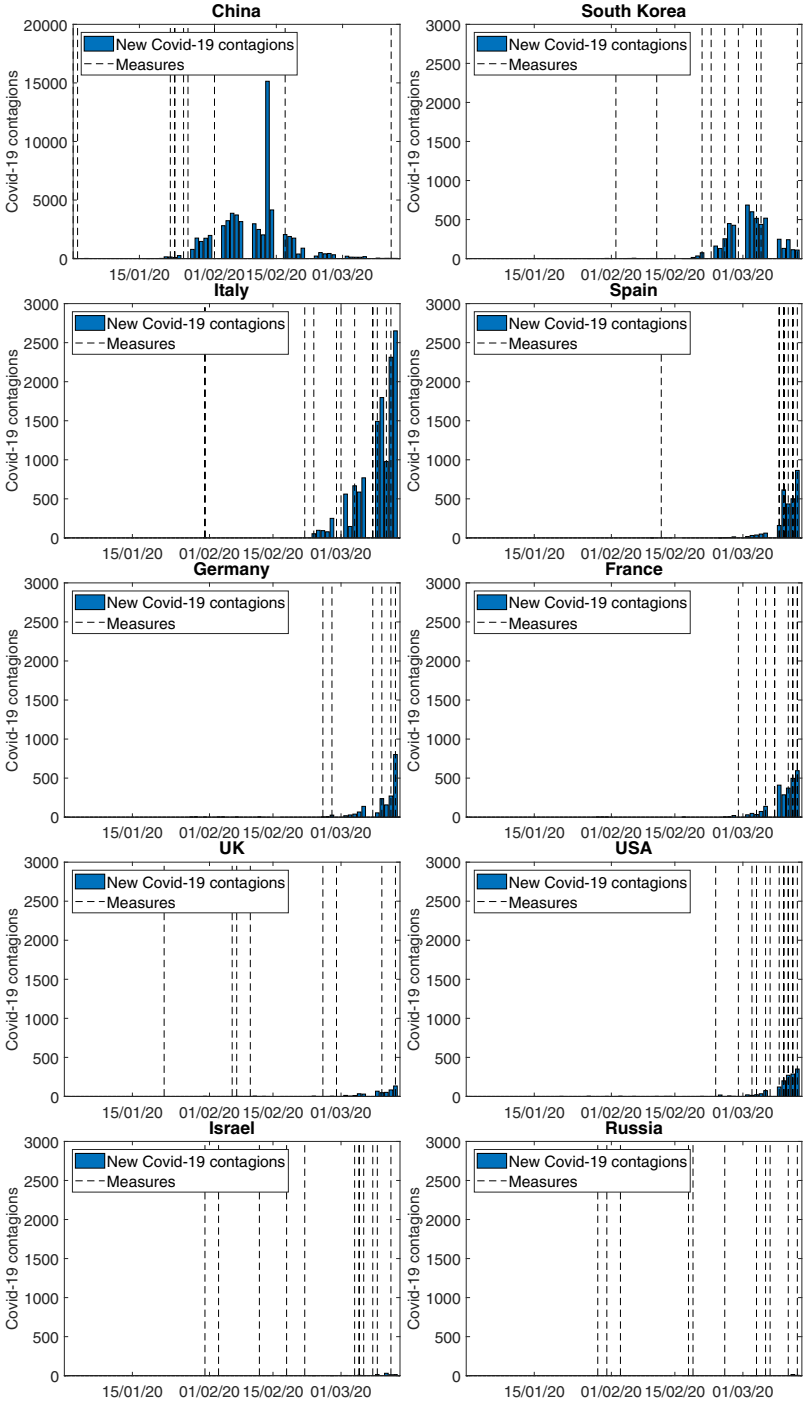

Fig. 2 Number of new daily infections (blue bar) and the date of anti-contagion measures (dashed line)

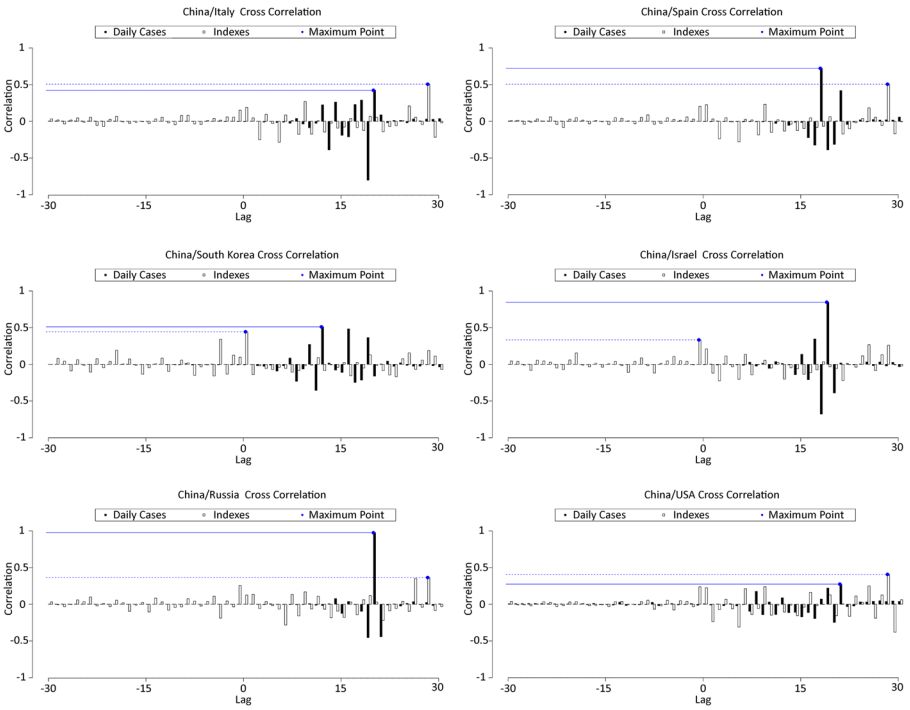

Fig. 3 Cross-correlations with respect to Chinese values. Black bars represent the cross-correlation between the **growth rate of the** number of new daily infections; white bars shows the cross-correlation between **returns of the** stock indexes. The maximum value reached by the correlation of infections (indexes) is identified by a solid (dashed) blue line

About 15–20 days after the outbreak of the COVID-19 in China, the infection spreads to other countries as shown by black bars in Fig. 3. It is in the few days following the spread of the pandemic that we re-observe a strong realignment between the financial series confirming the interconnection among markets and the onset of the systemic risk. The relevance of the economic interconnection and the systemic risk becomes more evident considering the chinese relationship with Israel and South Korea. In these cases, the financial market collapse is synchronized (at $t = 0$) with the Chinese stock market. It can be argued that the economies of these countries are highly interconnected and then, despite the delay of the cross-country spread of contagion, the financial repercussions are instantaneous. In our highly globalized world, the cross-correlations evidence that approximately 15–20 days have been needed to spread the pandemic and just 20 days to bring down all markets. Obviously, considering Italy as the trigger point and, therefore, considering the pandemic spread since its arrival in Europe, the whole process speeds up even further and, the "previous 15–20 days" become the "day after tomorrow," as shown in Fig. 4 where the highest correlations between the number of new daily infections in Italy and the lagged number of infection in other countries (black bars)[8], and between the MIB and the other stock indexes

[8]Results on the correlations between other countries are omitted, but similar in spirit.

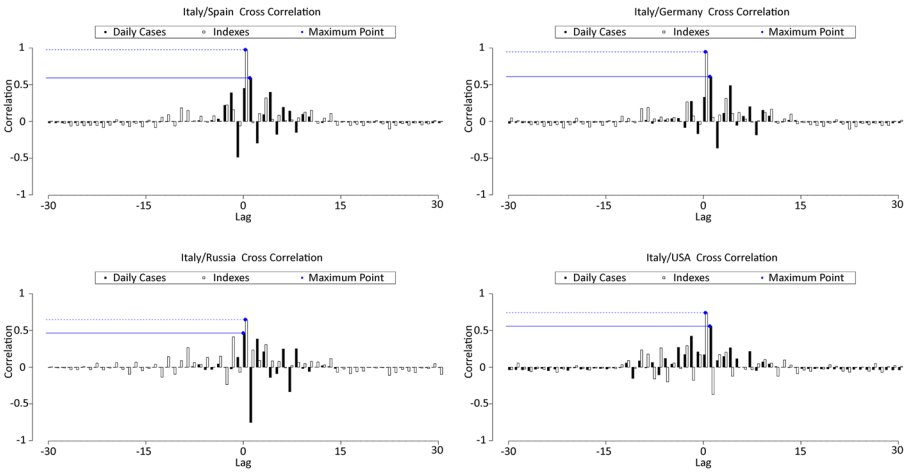

Fig. 4 Cross-correlations with respect to Italian values. Black bars represent the cross-correlation between the growth rate of the number of new daily infections; white bars shows the cross-correlation between returns of the stock indexes. The maximum value reached by the correlation of infections (indexes) is identified by a solid (dashed) blue line

(white bars) are found at lags 1 and 2. Here, it is possible to observe how the correlation between the daily changes of cases starts to increase before the joint financial collapse (i.e., before the point of highest correlation among the financial returns).

2.2 COVID-19 flood and disaster management

In this section, we analyze the financial markets reaction to policy measures implemented to deal with the virus spread. To this end we apply the augmented AR(1)-EGARCH(1,1) model (Karafiath 1988; Hansen and Lunde 2005; Malik 2011), which is traditionally used to examine the effect of different shocks affecting financial markets, such as good or bad news, policy measures and calendar effects (Aharon and Qadan 2019; Malik 2011; Vidal-Tomás and Ibañez 2018; Zaremba et al. 2020).[9] The model specification is:

$$\begin{aligned} r_{i,t} &= \mu + \beta_1 r_{i,t-1} + \beta_2 pm_{i,t} + \varepsilon_{i,t}, \quad \varepsilon_{i,t} = h_{i,t} z_{i,t}, \quad z_{i,t} \sim i.i.d.N(0,1), \\ \log\left(h_{i,t}^2\right) &= \omega + \alpha \left|\varepsilon_{i,t-1}/h_{i,t-1}\right| + \gamma\left(\varepsilon_{i,t-1}/h_{i,t-1}\right) + \rho \log\left(h_{i,t-1}^2\right), \end{aligned} \tag{1}$$

where $r_{i,t}$ denotes the return of the stock index i at day t, pm_t the dummy variable identifying security measures, $\varepsilon_{i,t}$ the error term, $z_{i,t}$ the white noise and $h_{i,t}^2$ the conditional variance given by the EGARCH model. Moreover, in relation to the conditional variance, α represents the magnitude of the variance shock, γ the sign effect and ρ the persistence of the shock volatility. Finally, the parameters β_1 and β_2 capture the market trend and the effect of the anti-COVID security measures, respectively.

[9] Given that the financial literature provides scholars with many different GARCH models able of capturing asymmetric effects, it could be also possible to use other alternatives such as GJRGARCH or APARCH models.

Table 1 *P*-values of pre- and post-estimation tests

Pre-estimation tests	MIB	IBEX35	DAX	CAC40	FTSE100	SP500	TA125	MOEX	SHANGAI	KOSPI
Arch(5)	0	0	0	0	0	0	0	0	0.98	0.15
Post-estimation tests	**MIB**	**IBEX35**	**DAX**	**CAC40**	**FTSE100**	**SP500**	**TA125**	**MOEX**	**SHANGAI**	**KOSPI**
Arch(5)	0.90	0.53	0.98	0.82	0.77	0.42	0.25	0.44	–	–
$Q^2(10)$	0.75	0.98	0.49	0.99	0.95	0.44	0.78	0.19	–	–

In order to capture the immediate effect (i.e., the impact of each policy on the announcement day) and the gradual effect (i.e., the reaction including the rumors of the day before and the consequence of the day after) of the anti-COVID measures, we consider two measures of abnormal returns in the model (1). Considering the day of the announcement t, we include a dummy pm_t equal to 1 on the announcement day t (and 0 otherwise) to calculate the abnormal returns in that day (AR_0). In the other specification, pm_t is equal to $\frac{1}{3}$ on days $t-1$, t, and $t+1$ (and 0 otherwise), and we measure the cumulative abnormal returns on those days ($CAR_{(-1,1)}$).[10]

The pre-estimation test on the time series returns and post-estimation tests for the AR(1)-EGARCH(1,1) model are shown in Table 1. As the reader can observe, in the pre-estimation test, no ARCH effect emerges in Chinese (Shangai) and South Korean (KOSPI) indices, and therefore these two time series are removed from the sample.[11] As regards the post-estimation test, instead, we observe that all other indices are estimable with the chosen model. Interestingly enough, we also observe that most of the indices are characterized by a statistically significant presence of asymmetry (γ), which supports the choice of the EGARCH model as a good candidate to represent the dynamics of the conditional volatility (Hansen and Lunde 2005).[12]

Let us now present the estimation of the AR(1)-EGARCH(1,1) model parameters, that is β_1 and β_2. Results are reported in Table 2, where the values of the parameters resulting from model estimation in the AR_0 and $CAR_{(-1,1)}$ specification are shown. Firstly, as expected, the β_1 parameter in the AR_0 specification is not statistically significant for all the stock returns except for the Russian one (i.e., MOEX). This result on asset returns has been widely documented (Cont 2001; Tedeschi et al. 2009) and is often cited as support for the "Efficient Market Hypothesis" (Fama 1965). By observing the lagged model specification (i.e., $CAR_{(-1,1)}$), the estimated value of the β_1 parameter, while remaining in many cases not statistically significant, shows a general mean reversal dynamics.

[10] Unfortunately, it is not possible to insert a regressor estimating and isolating the effect of the growth rate of infection, given the imperfect collinearity between cases and COVID-19 measures. For instance, the correlation between USA cases and COVID-19 policies is around 70%. Considering that policies were generally adopted in correspondence of an increase in events, we decided to use a single proxy to capture the "COVID effect" on markets

[11] At any rate, we include the results regarding Chinese (Shangai) and South Korean (KOSPI) indices in Appendix 2.

[12] Results on the conditional variance are shown in Appendix 2.

Table 2 Estimates of the AR-EGARCH model (1) analyzing the effect of the measures on day t (AR_0), and analysing the effect of the measures on a window of 1 day $CAR_{(-1,1)}$

AR(0)	SP500	FTSE100	DAX	CAC40	MIB	IBEX35	MOEX	TA125
β_1	− 0.0012	0.0555	− 0.0393	0.1741	0.2037	0.1265	− 0.1315***	0.2016
	(0.1062)	(0.1308)	(0.0710)	(0.1147)	(0.1035)	(0.1288)	(0.0488)	(0.1258)
β_2	− 0.0025	0.0024	− 0.0174***	− 0.0161***	− 0.0244***	− 0.0229**	− 0.0048***	− 0.0179
	(0.0064)	(0.0034)	(0.0045)	(0.0062)	(0.0072)	(0.0093)	(0.0016)	(0.0062)
CAR(-1,1)	SP500	FTSE100	DAX	CAC40	MIB	IBEX35	MOEX	TA125
β_1	− 0.4734***	− 0.2885***	− 0.0244	− 0.1591	− 0.1881*	− 0.2144	− 0.0868	− 0.3249**
	(0.0506)	(0.0793)	(0.0679)	(0.1316)	(0.0953)	(0.1380)	(0.0527)	(0.1628)
β_2	− 0.0071	− 0.0024	− 0.0486***	− 0.0738**	− 0.1113***	− 0.0327**	− 0.0091	− 0.0078
	(0.0078)	(0.0059)	(0.0073)	(0.0292)	(0.0190)	(0.0146)	(0.0034)	(0.0191)

On the other hand, as regards the estimated value of the parameter capturing the effect of anti-COVID measures on financial returns, β_2, we observe a clear separation between infected and (apparently) less infected countries, i.e., Italy, Spain, Germany and France, vs the UK, the USA, Israel and Russia. In both model specifications we have a statistically significant negative effect of policies on the financial returns of those countries most affected by the pandemic. Moreover, interestingly enough, the value of the parameter estimated with the lagged model specification (i.e., $CAR_{(-1,1)}$) always displays a statistically more negative impact than that estimated with the AR_0 one. This fact has a double interpretation. On the one hand, it suggests that the implemented measures are anticipated by the markets. On the other hand, the fact that poorly affected countries are statistically insensitive to anti-COVID policies strengthens the hypothesis of their perceived preventive uselessness.

3 Concluding remarks

Our analysis has shown that the COVID-19 attack on financial markets brought back to light the well-known phenomenon of systemic risk. In fact, we have proven that the onset of the virus has caused a sudden and simultaneous fall in financial markets, possibly due to the strong interconnections among them. Whereby the pandemic has taken about 15 days to spread from eastern countries to western one, once in Europe, the contagion has hit almost all markets in unison.

Moreover, our retrospective analysis shows how policy measures did not calm down investors panic. At least in the short run, the collateral components of such measures were predominant in shaping expectation. Although our results are still quite preliminary, they capture two interesting points. The first concerns the direction of the attack. The virus-induced economic and financial crisis highlights the increasingly complex systemic interaction which dominates in modern socio-economic systems. The second key point is that, as in the previous crisis, long-term oriented policy measures can not lessen short-term financial pessimism.

Plausibly, the coordination failure of country-specific policy led to a delay in the containment of the initial contagion, since, as shown, most of the countries begun to apply massively anti-contagion measures only once the infection started in their own territory, without anticipating the virus intrusion. In the era of globalization, the pandemic outbreak is more likely to be a common necessary evil rather than an isolated country-specific problem. Once more the systemic risk has been faced in an uncoordinated and unidirectional way without applying the science of complexity, which recommends studying the socio-economic system starting with the coevolution of its sub-systems and not breaking it down into disjointed, non-communicating sub-spheres (see Tedeschi et al. 2020 for further references). Once again, the past experience quickly fell into oblivion and Mr.Trichet' s words went unheard: "the key lesson we would draw from our experience is the danger of relying on a single tool, methodology or paradigm. Policy-makers need to have input from various theoretical perspectives and from a range of empirical approaches... we need to develop complementary tools to improve the robustness of our overall framework."

Appendix 1

Table 3 Description of the events for each country

China	Date	Event
1	31/12/2019	The two emergent notice letters from the Municipal Health Commission of Wuhan began to circulate on the Internet which were soon confirmed by Wuhan CDC who admitted that there were 27 cases of pneumonia of unknown cause on December 31.
2	01/01/2020	On January 1, 2020, the seafood market was closed down by Jianghan District's Health Agency and Administration for Market Regulation.
3	22/01/2020	Wuhan airport and railway stations are temporary closed.
4	23/01/2020	China: 2019-nCoV lockdown extended to Ezhou, Huanggang, Chibi and Zhijiang (Hubei province).
5	23/01/2020	The Beijing Culture and Tourism Bureau cancels all large-scale Lunar New Year celebrations in an effort to contain the growing spread of Wuhan coronavirus. On the same day, Chinese authorities enforce a partial lockdown of transport in and out of Wuhan. Authorities in the nearby cities of Huanggang and Ezhou Huanggang announce a series of similar measures.
6	25/01/2020	Travel restrictions were imposed on a further five cities in Hubei, taking the overall number of people affected to 56 million.
7	26/01/2020	The China Association of Travel Services reports that all tours, including international ones, will be suspended.
8	01/02/2020	Hubei's lockdown.
9	17/02/2020	Hubei province authorities issue new restrictions.
10	12/03/2020	Implementation of new restriction measures for travellers.
France	**Date**	**Event**
11	29/02/2020	Ban on gatherings of more than 5000 people.
12	04/03/2020	Haut-Rhin announces the ban on public gatherings in Bernwiller and Hésingue.
13	06/03/2020	New measures have been taken in the Haut-Rhin.
14	08/03/2020	Ban on gatherings of more than 1000 people.
15	08/03/2020	The prefects of Corsica and Corse-du-Sud announce a set of measures.

Table 3 (continued)

18	12/03/2020	The European Central Bank announced an injection of 120,000 million euros in the 'euro zone' through the extra purchase of assets.
19	13/03/2020	Ban on gatherings of more than 100 people.
20	13/03/2020	Prohibition for ships carrying more than 100 passengers from calling or anchoring in inland and territorial waters.

Germany	Date	Event
16	11/03/2020	The prefect of Hérault decided to close all educational establishments, all crèches and all structures welcoming children under the age of 15, in the territory of 16 municipalities to the north and east of Montpellier.
17	12/03/2020	Closure of schools and higher education.
21	26/02/2020	On 26 February, following the confirmation of multiple COVID-19 cases in North Rhine-Westphalia, Heinsberg initiated closure of schools, swimming pools, libraries and the town hall until 2 March.
22	28/02/2020	Heinsberg extended closure of daycare facilities and schools to 6 March. The officials imposed a 14-day home isolation for people who had had direct contacts with individuals in the current cases as well as people who showed flu symptoms. Lufthansa cut the number of short- and medium-haul flights by up to 25%, and removed multiple long-haul routes resulting in 23 long-haul aircraft being taken out of operation. On the same day, Germany enacted new health security measures to include regulations for air and sea travel, requiring passengers from China, South Korea, Japan, Italy and Iran to report their health status before entry. Train railway companies must report passengers with symptoms to authorities and the federal police would step up checks within 30 kilometres of the border.
23	08/03/2020	On 8 March, the German Health Minister recommended cancelling events with more than 1000 attendees for the time being.
24	10/03/2020	In reaction to a general ban on events with more than 1,000 participants put into immediate effect by several federal states, Germany's Ice Hockey league DEL announced that the 2019/2020 season would be cancelled immediately, and that the championship title would remain vacant this season. Several matches of the football leagues, including all Bundesliga matches of matchday 26, were announced to be played behind closed doors, a first in the 57-year history of the Bundesliga.
25	12/03/2020	The European Central Bank announced an injection of 120,000 million euros in the 'euro zone' through the extra purchase of assets.
26	13/03/2020	On 13 March, 14 of the 16 German federal states decided to close their schools and nurseries for the next few weeks. Germany's neighbours Czech Republic, Poland and Denmark closed their borders. The government decided to give financial support to artists, private cultural institutions and event companies that struggle in the crisis.

Table 4 Description of the events for each country

Israel	Date	Event
27	31/01/2020	Israel suspend all flight from China.
28	03/02/2020	Entry restriction to non-resident.
29	12/02/2020	New travels restriction.
30	18/02/2020	Quarantine for Thailand, Hong Kong and Macao travelers.
31	22/02/2020	On 22 February, Israel instituted a 14-day home isolation rule for anyone who had been in South Korea or Japan. Israel also barred the entry of non-residents or citizens of Israel who were in South Korea during the 14 days prior to their arrival in Israel. The same directive was applied to those arriving from Japan starting 23 February.
32	04/03/2020	Implementation of new quarantine measures.
33	05/03/2020	West Bank authorities declare the state of emergency.
34	05/03/2020	Implementation of new quarantine measures.
35	06/03/2020	Betlemee placed in lockdown.
36	08/03/2020	Government orders mandatory self-quarantine for all travellers.
37	09/03/2020	On 9 March, Prime Minister Benjamin Netanyahu declared a mandatory quarantine for all people entering Israel, requiring all entrants to quarantine themselves for fourteen days upon entering the country.
38	12/03/2020	On 12 March, Israel announced that all universities and schools would close until after the Passover (spring) break.
Italy	**Date**	**Event**
39	31/01/2020	Air traffic suspended to and from China.
40	31/01/2020	On 31 January 2020, the Italian Council of Ministers appointed Angelo Borrelli, head of the Civil Protection, as Special Commissioner for the COVID-19 emergency.

Table 4 (continued)

41	22/02/2020	The government announced a new decree imposing the quarantine of more than 50,000 people from 11 different municipalities in Northern Italy. The Italian military and law enforcement agencies were instructed to secure and implement the lockdown.
42	24/02/2020	Multiple regions in Italy decided to close all schools and universities for two days to a week.
43	29/02/2020	Institutional closures extendend.
44	01/03/2020	On 1 March, the Council of Ministers approved a decree to organise the containment of the outbreak. In the decree, the Italian national territory was divided into three areas.
45	04/03/2020	The Italian government imposed the shutdown of all schools and universities nationwide for 2 weeks.
46	08/03/2020	Flight suspension from and to Milano Malpensa.
47	08/03/2020	In the night between 7 and 8 March, the government approved a decree to lock down Lombardy and fourteen other provinces in Veneto, Emilia-Romagna, Piedmont and Marche, involving more than 16 million people.
48	09/03/2020	Conte announced in a press conference that all measures previously applied only in the so-called red zones had been extended to the whole country.
49	11/03/2020	The government allocated 25 billion euros for the emergency. In the evening, Conte announced a tightening of the lockdown, with all commercial and retail businesses except those providing essential services, like grocery stores and pharmacies, closed down.
50	12/03/2020	The European Central Bank announced an injection of 120,000 million euros in the 'euro zone' through the extra purchase of assets.
Russia	**Date**	**Event**
51	29/01/2020	Officials close borders with China.
52	31/01/2020	On 31 January, Deputy Prime Minister Tatiana Golikova said Russia will restrict the entry of foreigners arriving from China, except for flights to Moscow Sheremetyevo Airport.
53	03/02/2020	State railway suspends trains to China.

Table 4 (continued)

54	18/02/2020	Aeroflot reduces flight operations to China and Hong Kong.
55	19/02/2020	Chinese citizens to be barred entry into Russia from February 20.
56	26/02/2020	Flights suspension from South Korea.
57	04/03/2020	On 4 March, Russia has temporarily banned the export of medical masks, gloves, bandages and protective suits.
58	06/03/2020	On 6 March, Moscow Mayor Sergei Sobyanin announced a "high alert regime," ordering self-isolation for 2 weeks for Russians returning from China, South Korea, Iran, France, Germany, Italy and Spain. Rospotrebnadzor announced Russia has conducted 51,366 tests for the coronavirus nationwide.
59	07/03/2020	Aeroflot suspends flights to Hong Kong.
60	11/03/2020	Aeroflot announces more flight suspensions amid COVID-19 outbreak.
61	13/03/2020	Ministry of Education recommended regions to switch the educational process to distance learning if it is necessary. According to RBK, Moscow recommended that private schools go on a 2-week vacation or switch to distance learning.

Table 5 Description of the events for each country

South Korea	Date	Event
62	02/02/2020	South Korean officials announced that the country would ban the entry of foreigners who have recently visited China's Hubei province.
63	11/02/2020	Strict quarantine screening measures for travelers arriving from China, Hong Kong, and Macau.
64	21/02/2020	Government designates Daegu and Cheongdo as "special care zones."
65	23/02/2020	The Daegu Office of Education decided to postpone the start of every school in the region by 1 week.
66	26/02/2020	Several governments issue travel restrictions to and from South Korea due to the ongoing coronavirus outbreak.
67	29/02/2020	The government announced that it would supply 4.48 million masks in one day.
68	04/03/2020	South Korea announced a stimulus package of 11.7 trillion won (S$13.7 billion) on Wednesday (March 4) to cushion the impact of the largest outbreak of coronavirus outside China as efforts to contain the disease worsen supply disruptions and sap consumption.
69	05/03/2020	Ministry of Health announces new "special care zone" in Gyeongsan city (North Gyeongsang province).
70	13/03/2020	Daegu and Gyeongbuk are declared special disaster zones.
Spain	**Date**	**Event**
71	12/02/2020	Barcelona's Mobile World Congress was cancelled.
72	09/03/2020	Basque government announces the closing of all schools in the municipalities of Vitoria and Labastida.
73	09/03/2020	President of the regional government of Madrid, Isabel Díaz Ayuso, announces the cancellation of classes in the Autonomous community of Madrid at all educational levels due to the strong increase in cases in the region.
74	10/03/2020	The Government of Spain decreed the immediate cancellation of all direct flights from Italy to Spain until 25 March.
75	10/03/2020	Regional government of La Rioja announces the suspension of classes for a period of 2 weeks.
76	10/03/2020	The Constitutional Court suspends its activity for the following two days.
77	10/03/2020	Spanish Government suspends events with more than one thousand attendants in Madrid, La Rioja and Vitoria.
78	10/03/2020	The Valencian Government decides to postpone the Falles of Valencia for fifth time in its history and the Magdalena, in Castellón.

Table 5 (continued)

79	11/03/2020	Catalan government follows the steps of the Spanish government on the previous day and suspends events with more than one thousand attendants in the region.
80	12/03/2020	Catalan Government orders the confinement of the city of Igualada and the towns of Vilanova del Camí, Òdena and Santa Margarida de Montbui after Igualada Hospital became a contagion focus. This first measure in Spain will affect 70,000 people during 14 days.
81	12/03/2020	Nationwide closure of schools after all Autonomous Communities order it. More than 10 million students (1 million from university and 9 million from schools) ordered to stay at home for a period of 2 weeks.
82	12/03/2020	The European Central Bank announced an injection of 120,000 million euros in the 'euro zone' through the extra purchase of assets.
83	13/03/2020	Prime Minister of Spain Pedro Sánchez announces the declaration of the state of emergency in the nation for a period of 15 days, to become effective next day after the approval of the Council of Ministers.
UK	Date	Event
84	22/01/2020	Heathrow Airport received additional clinical support and tightened surveillance of the three direct flights that it receives from Wuhan every week; each were to be met by a Port Health team.
85	06/02/2020	Following confirmation of his result, the UK's CMOs expanded the number of countries where a history of previous travel associated with flu-like symptoms—such as fever, cough and difficulty breathing—in the previous 14 days would require self-isolation and calling NHS 111. These countries included China, Hong Kong, Japan, Macau, Malaysia, Republic of Korea, Singapore, Taiwan, Thailand.
86	07/02/2020	All flights between Manchester Airport (MAN) and mainland China suspended .
87	10/02/2020	The Secretary of State for Health and Social Care, Matt Hancock, announced the Health Protection (Coronavirus) Regulations 2020, to give public health professionals "strengthened powers" to keep affected people and those believed to be a possible risk of having the virus, in isolation.
88	26/02/2020	Containment measures implemented for passengers arriving from South Korea.
89	29/02/2020	British Airways to reduce flights to Italy, Singapore, and South Korea.
90	10/03/2020	British Airways temporarily cancels flights to/from Italy.
91	13/03/2020	Many sporting fixtures including the London Marathon, the Six Nations Wales vs Scotland fixture, and all Premier League and EFL football games were postponed and the 2020 United Kingdom local elections were postponed for a year.

Table 6 Description of the events for each country

USA	Date	Event
92	24/02/2020	The Trump administration asked Congress for $2.5 billion in emergency funding to combat the outbreak.
93	29/02/2020	Travel restrictions imposed on Iran, Italy, and South Korea.
94	03/03/2020	Federal Reserve chairman Jerome Powell announced a 0.5 percentage point (50 basis point) interest rate cut in light of "evolving risks to economic activity" from the coronavirus.
95	04/03/2020	Los Angeles county (California state) confirmed six new cases of coronavirus disease (COVID-19) on Wednesday, March 4, prompting officials to declare a local emergency.
96	04/03/2020	Governor David Ige declared a state of emergency (Hawaii).
97	04/03/2020	The governor of California state, Gavin Newsom, declared a health emergency after the first coronavirus (COVID-19)-related death was confirmed in the state on Wednesday, March 4.
98	06/03/2020	Governor Eric Holcomb declared a public health emergency due to the first positive Indiana case.
99	07/03/2020	Cuomo declared a state of emergency in New York state.
100	09/03/2020	Proclamation of Disaster Emergency signed by Governor (Iowa).
101	10/03/2020	New York Governor Andrew Cuomo announced on Tuesday, March 10, that schools, houses of worship, and large gathering areas in New Rochelle (New York state) will be closed from Thursday, March 12.
102	10/03/2020	Governor Polis declared a state of disaster emergency.
103	10/03/2020	Governor Ned Lamont declared a public health emergency after two residents tested positive for coronavirus.
104	11/03/2020	Public health emergency announced by Governor Doug Ducey (Arizona).
105	11/03/2020	Governor Michelle Lujan Grisham declared a state of emergency (New Mexico).
106	12/03/2020	Governor John Carney declared a state of emergency following three more confirmed cases (Delaware).
107	12/03/2020	The Fed announced on March 12 that it would also expand its purchases of bonds and other measures valued at $1.5 trillion, to inject money into the banking system.
108	13/03/2020	On Friday, March 13, President Donald Trump declared a national emergency in the USA due to the ongoing outbreak of coronavirus disease.

Appendix 2

Table 7 Estimates of the AR-EGARCH model (Eq. 1) analyzing the effect of the measures on day t (AR_0), and analyzing the effect of the measures on a window of 1 day $CAR_{(-1,1)}$

AR(0)	SP500	FTSE100	DAX	CAC40	MIB	IBEX35	MOEX	TA125	SHANGAI	KOSPI
β_1	− 0.0012	0.0555	− 0.0393	0.1741	0.2037	0.1265	− 0.1315***	0.2016	− 0.1266**	− 0.0414
	(0.1062)	(0.1308)	(0.0710)	(0.1147)	(0.1035)	(0.1288)	(0.0488)	(0.1258)	(0.0549)	(0.3045)
β_2	− 0.0025	0.0024	− 0.0174***	− 0.0161***	− 0.0244***	− 0.0229**	− 0.0048***	− 0.0179	− 0.0137**	0.0064
	(0.0064)	(0.0034)	(0.0045)	(0.0062)	(0.0072)	(0.0093)	(0.0016)	(0.0062)	(0.0062)	(0.0090)
ω	− 0.2139	− 15.4389***	− 12.3040***	− 9.4553***	− 7.3485***	− 5.6756***	− 16.6699***	− 11.8822***	− 10.5957***	− 0.9827
	(0.1857)	(0.0003)	(0.9285)	(1.1273)	(0.7682)	(1.0943)	(0.5337)	(1.5178)	(2.3792)	(0.7550)
α	− 0.8994***	1.5211***	1.2541***	1.6799***	1.8650***	1.7307***	− 1.1026***	0.3047	− 0.7231*	− 0.8801
	(0.2609)	(0.2831)	(0.3455)	(0.3296)	(0.3446)	(0.3325)	(0.3455)	(0.2610)	(0.3877)	(0.3040)
γ	− 1.1004***	− 0.7731***	0.4791**	0.4934*	0.0159	0.6117**	− 1.0647***	− 0.4740*	− 0.5837***	− 0.6655
	(0.1610)	(0.2706)	(0.1875)	(0.2970)	(0.2188)	(0.2728)	(0.1964)	(0.2463)	(0.1646)	(0.2390)
ρ	0.9068***	− 0.5983***	− 0.4479***	− 0.0289	0.2588***	0.4377***	− 1.0368***	− 0.3557**	− 0.3198	0.8232
	(0.0000)	(0.0428)	(0.1200)	(0.1483)	(0.0992)	(0.1173)	(0.0504)	(0.1690)	(0.3059)	(0.1050)
CAR(-1,1)	SP500	FTSE100	DAX	CAC40	MIB	IBEX35	MOEX	TA125	SHANGAI	KOSPI
β_1	− 0.4734***	− 0.2885***	− 0.0244	− 0.1591	− 0.1881*	0.2144	− 0.0868	0.3249**	0.1810	− 0.0379
	(0.0506)	(0.0793)	(0.0679)	(0.1316)	(0.0953)	(0.1380)	(0.0527)	(0.1628)	(0.1145)	(0.1444)
β_2	− 0.0071	− 0.0024	− 0.0486***	− 0.0738**	− 0.1113***	− 0.0327**	− 0.0091	− 0.0078	− 0.0109	0.0054
	(0.0078)	(0.0059)	(0.0073)	(0.0292)	(0.0190)	(0.0146)	(0.0034)	(0.0191)	(0.0083)	(0.0094)

Table 7 (continued)

ω	− 6.5039***	− 12.7056***	− 8.1197***	− 9.4894***	− 1.7784	− 9.3971***	− 15.6597***	0.1125	− 0.5924***	− 0.4077**
	(0.5244)	(0.5911)	(0.4579)	(1.9657)	(1.7405)	(1.2578)	(0.8055)	(2.2887)	(0.1512)	(0.1940)
α	1.7036***	1.1483***	2.5163***	1.3459***	0.7774**	1.5648***	− 1.4357***	− 0.2276	− 0.9988***	− 0.7399**
	(0.2132)	(0.2336)	(0.4081)	(0.3506)	(0.3878)	(0.3777)	(0.4683)	(0.6504)	(0.1138)	(0.3560)
γ	− 0.9325***	− 0.8445***	0.0036	0.3947	0.6960**	0.6520***	− 1.1212***	− 0.1800	− 0.6851**	− 0.5379**
	(0.2466)	(0.1672)	(0.2874)	(0.4474)	(0.3242)	(0.2300)	(0.2482)	(0.5977)	(0.3164)	(0.2440)
ρ	0.3889***	− 0.3636***	0.2076***	− 0.0668	0.8644***	− 0.0635	− 0.9553***	0.9841***	0.8504***	0.8968***
	(0.0645)	(0.0668)	(0.0634)	(0.2555)	(0.1973)	(0.1774)	(0.0833)	(0.1858)	(0.0000)	(0.0000)

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