The impact of COVID-19 on global stock markets: early linear and non-linear evidence for Italy

Theodoros Daglis¹ · Ioannis G. Melissaropoulos¹ ·
Konstantinos N. Konstantakis¹ · Panayotis G. Michaelides¹

Received: 29 January 2021 / Accepted: 1 November 2021 / Published online: 15 November 2021
© Japan Association for Evolutionary Economics 2021

Abstract

The scientific community still struggles to understand the magnitude of the world-wide infections and deaths induced by COVID-19, partly ignoring the financial consequences. In this paper, using the autoregressive fractionally integrated moving average (ARFIMA)—general autoregressive conditional heteroskedasticity (GARCH) model, we quantify and show the impact of the COVID-19 spread in Italy, utilizing data for the stock market. Using information criteria and forecasting accuracy measures, we show that the COVID-19 confirmed cases contribute with statistically significant information to the modeling of volatility, and also increase the forecasting ability of the volatility of the Italian stock market index, leading to a decrease in the mean stock index.

Keywords COVID-19 · Stock market · Italy

JEL Classification C22 · C58 · C50 · C51

1 Introduction

The pandemic of the so-called coronavirus disease (COVID-19) has gained a global character as it has spread from one country to another, having its origin in Wuhan-Hubei, China (Liu et al. 2020). The fact that the total confirmed COVID-19 cases amount to several millions globally, underlines the importance of this pandemic (WHO 2020). In fact, the case of COVID-19 is unique, differing in many ways from previous disease spread, for instance the severe acute respiratory syndrome (SARS)

✉ Panayotis G. Michaelides
pmichael@central.ntua.gr

¹ Laboratory of Theoretical and Applied Economics and Law, Department of Humanities, Social Sciences and Law, School of Applied Mathematical and Physical Sciences, National Technical University of Athens, Athens, Greece

spread in 2003 (Wilder-Smith et al. 2020), or the H1N1 virus of 2009. However, thus far, the financial consequences of such a pandemic remain less widely discussed.

Studies on the macroeconomic effects of other epidemics, for instance the one caused by the SARS virus in 2003, have shown significant effects on the total economy, through large reductions in consumption of various goods and services, increases in business operating costs, and re-evaluation of country risks reflected in increased risk premia (McKibbin and Fernando 2020). In addition, due to the global trade and financial integration, these shocks were also transmitted to other economies as well, whereas the degree of contagion between the different economies varied according to the strength of financial and trade relationships among them. In general, in the case of previous epidemics, global costs were significant (Lee and McKibbin 2004).

To cast a glimpse on the economic consequences of such a situation, in terms of monetary units, previous studies showed that the economic effect of influenza on the US economy is estimated to be around \$73.1–\$166.5 billion (Meltzer et al. 1999). In fact, many economies in their attempt to put a halt to the spread of COVID-19, imposed the closing of many businesses, markets, etc. Other measures that were enforced included the suspension of all entry of immigrants and non-immigrants that had travelled to high-risk zones (The White House 2020). Furthermore, many countries suspended several public transport services across the border (Sohrabia et al. 2020). Even the Olympic games, an event of high importance (Gallego et al. 2020), were postponed.

Of course, the financial system, which is a crucial part of the economic system, also faces the adverse consequences of a pandemic. In fact, the financial markets are the first that capitalized the risk induced by the pandemic. A prominent study by Donadelli et al. (2017), showed that the declaration of pandemics, induced by the SARS-COV-2 and the H1N1 virus, had a positive impact on the stock market index of pharmaceuticals that were likely to develop a vaccine and a negative effect on associated stock prices of other firms in different sectors.

Regarding the COVID-19 pandemic, several studies show that stock market indices of various economies experienced a negative longstanding effect. See among others, Ashraf (2020), Albuquerque et al. (2020), Cheng (2020), Gormsen and Koijen (2020), Ramelli and Wagner (2020). Nonetheless, most of these studies, examine the impact of the pandemic just by comparing stock exchange data during the COVID-19 period and the pre-pandemic period. Therefore, a mechanism on how the exogenous effect of the pandemic impacts the stock market is still vague in the literature.

The facts on the early pandemic stage show that the stock markets of various economies started to experience sudden drops in their overall price index before the 11th of March 2020, when the recent situation was declared to be a pandemic. These market drops are associated with negative news regarding the evolution of COVID-19 and the sudden increase in COVID-19 incidents globally (Akhtaruzzaman et al. 2020; Baket et al. 2020). In other words, the stock markets capitalized the increased exogenous risk from the pandemic, due to the fact that investors anticipated that the spread of the virus will force policy actors to take lockdown measures to secure public health (Haroon and Rizvi 2020; Hoshikawa and Yoshimi 2021). As a result,

the lockdown measures will decrease consumption and production diminishing at the same time the margin profits of firms and thus the overall expected return of investors' portfolio. This mechanism describes compactly how the evolution of the pandemic directly affected the stock market index of various economies.

In this paper, for the first time in the literature, using relevant econometric and forecasting techniques, to test the direct effect of the pandemic on the stock market index, we model the impact of COVID-19 confirmed cases on the stock market index. To do so, we will focus on a European stock market that was severely hit in the early stages of the pandemic, namely the Italian stock market. Based on official data that come from the Central Bank of Italy, the Italian stock market faced the eighth most extreme drop in its history in February 2020, when the pandemic in Italy was expanding rapidly (Just and Echaust 2020). Despite the efforts made by policy makers to suspend short-selling actions in the Italian stock market, on the 12th of March 2020, the Italian Stock market faced a tremendous drop of almost 17% (Statista Research Department, 23-11-2020). The aforementioned facts highlight our choice for selecting the Italian stock market as our primary field of research.

Next, to study the characteristics of the Italian stock market and their potential dependence from the pandemic, we make use of an autoregressive fractionally integrated model with a generalized autoregressive conditional heteroskedasticity error (ARFIMA-GARCH), we model the volatility of the stock market indices of the aforementioned economy.

Our modelling choice regarding the use of an ARFIMA GARCH model lies in previous attempts made in the literature of volatility modeling of stock markets. See, among others, Bekaert and Harvey (1997), Scheicher (2001) Syriopoulos (2007), Abdalla 2012, Daglis et al. (2020). Based on our findings, we witness a negative impact of COVID-19 on the Italian stock index, and an increase in its volatility, whereas both effects are statistically significant.

The paper is structured as follows: Sect. 2 sets out the methodology; Sect. 3 presents the results; finally, Sect. 4 concludes the paper.

2 Methodology

In this paper, we need to explicitly test whether the COVID-19 cases, reported daily, have an impact on the mean and variance of the Italian stock market index. In this context, based on relevant financial econometrics techniques, as a first step we define the naïve optimal model for the evolution of the Italian stock market index in the class of ARFIMA models. Then, by augmenting the model with a GARCH process that alleviates heteroskedasticity and fat-tails in the distribution of the stock market index, we assess whether COVID-19 cases have a statistically significant effect on the mean and volatility of the Index. In addition, for the sake of robustness, we check whether the alternative model, which consists of the naïve model, augmented with the exogenous variable of COVID-19 cases, has a better forecasting ability than the naïve model.

Following the econometric literature, we make use of a baseline autoregressive fractionally integrated moving average model (ARFIMA) for the Italian stock market index. The general form of an ARFIMA is the following:

$$y_t = \{p(L)\}^{-1}(1-L)^{-d}\theta(L)\varepsilon_t, \quad (1)$$

where: y_t is the respective time series, $p(L)$ is the lag polynomial of the time series, $\theta(L)$ is the moving average polynomial, L denotes the lag operator, d is the fractional parameter, and ε_t is the error term. Note that in our analysis, the time series under scrutiny is the Italian stock market index.

The fractional-integration parameter $d \in (-0.5, 0.5)$ captures the long-run effects, while the ARMA parameters capture the short-run effects. Of course, in case $d = 1$, then the time series is integrated of degree one, i.e. $I(1)$ and the ARFIMA model becomes an ARIMA model. See Beran (1994), Baillie (1996) and Palma (2007).

To study the possible existence of fractionally integrated time series, we make use of the popular Geweke and Porter-Hudak (GPH) test (1983). Next, using relevant information criteria, we select the number of autoregressive (AR) and moving average (MA) terms for each baseline model. Finally, to account for the potential heteroskedasticity in the residuals, we augment the ARFIMA model described in (1) with a generalized autoregressive conditional heteroskedasticity (GARCH) model (Bollerslev 1986). The GARCH (p, q) specification is of the form:

$$\sigma_t^2 = \omega + a_1\varepsilon_{t-1}^2 + \dots + a_q\varepsilon_{t-q}^2 + b_1\sigma_{t-1}^2 + \dots + b_p\sigma_{t-p}^2 = \omega + \sum_{i=1}^q a_i\varepsilon_{t-i}^2 + \sum_{j=1}^p b_j\sigma_{t-j}^2, \quad (2)$$

where: σ_t is the standard deviation of the residuals, $b_j, j = 1, \dots, p$ are the lagged coefficients, ε_t denotes the residuals obtained by the estimation of the ARFIMA model, $a_i, i = 1, \dots, q$ are the lagged coefficients, and ω is the fixed term which represents the mean variance of the residuals, where in Eq. (2) there are q lags of the squared error terms and p lags of the variance. Note that in our analysis, σ_t is the standard deviation of the residuals of the ARFIMA model that captures the evolution of the Italian stock market index, whereas ε_t denotes the residuals obtained by the estimation of the ARFIMA.

Therefore, to establish the lag length p and q of the GARCH (p, q), we make use of relevant information criteria, such as AIC, BIC, Shibata and Hannan-Quinn.

Next, to model the effect of COVID-19 cases on the various market indices, we introduce exogenous variables in the GARCH model (exogenous covariate). Therefore, we consider the volatility model:

$$y_t = \sigma_t\varepsilon_t, \quad (3)$$

and let Ω_t be the filtration representing the information set at time t . Then,

$$\text{Var}(y_{t+1}|\Omega_t) = \sigma_{t+1}^2, \quad (4)$$

We assume $\varepsilon_t \sim (0, 1)$ and is adapted to the information set available at time $t(\Omega_t)$ and σ_{t+1} is given by:

$$\sigma_{t+1}^2 = w + \alpha y_t^2 + \beta \sigma_t^2 + f(z_t, \pi). \quad (5)$$

For parameters $w, \alpha, \beta \in J \subset \mathbb{R}_+$ and it is assumed that $\sum_{i=1}^{\infty} a_i + \sum_{i=1}^{\infty} \beta_i < 1$. The $f(z_t, \pi)$ is assumed to be strictly positive and $\pi \in \mathbb{R}^d$. In the context of the model, the covariate z_t is a nearly integrated process. To ensure a positive effect of z_t , a logistic distribution function is employed:

$$F_x = \frac{1}{1 + e^x}, \quad (6)$$

and the density by:

$$\frac{d}{dx} F_x = \frac{e^{-x}}{1 + e^{-x}}. \quad (7)$$

In this work, we follow Park and Han (2012), who propose asymptotic theory of the maximum likelihood estimator for ARCH/GARCH model with persistent covariate, to establish consistency and obtain limit distribution. Note that the covariate in our analysis consists of the time series variable of COVID-19.

In this work, we compare the estimates of the baseline ARFIMA model with an alternative specification, which comprises an ARFIMA-GARCH model with exogenous variables, namely:

$$y_t = \{p_1(L)\}^{-1} (1 - L)^{-d} \theta(L) p_2(L) x_t \varepsilon_t, \quad (8)$$

where: y_t is the respective time series, $p_1(L)$ is the lag polynomial of the time series, $\theta(L)$ is the moving average polynomial, L denotes the lag operator, d is the fractional parameter, $p_2(L)$ is the lag polynomial for the exogenous time series variable x_t and ε_t is the error term.

Analytically, Eq. (8) can be written as follows:

$$\Delta^d y_t = \mu_t + \varepsilon_t, \quad (9a)$$

or

$$\Delta^d y_t = \mu + \kappa x_{t-1} + \sum_{i=1}^{p'} \varphi_i \Delta^d y_{t-i} + \sum_{j=1}^{q'} \theta_j u_{t-j} + \varepsilon_t, \quad (9b)$$

since μ_t , is:

$$\mu_t = \mu + \kappa x_{t-1} + \sum_{i=1}^{p'} \varphi_i \Delta^d y_{t-i} + \sum_{j=1}^{q'} \theta_j \Delta u_{t-j}, \quad (10)$$

and

$$u_{t-j} = \overline{\Delta^d y_{t-j+1}} - \overline{\Delta^d y_{t-j}}. \quad (11)$$

and σ_t , the variance part of the model, is:

$$\sigma_t = \omega + \sum_{i=1}^p \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^q \beta_j \sigma_{t-j}^2 + \gamma_1 x_{t-1}^2 + v_t. \quad (12)$$

In the case, for instance, of a GARCH (1, 1):

$$\sigma_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 + \gamma_1 x_{t-1}^2 + v_t, \quad (13)$$

where

$$\sigma_t^2 = E \left[(\Delta^d y_t - \mu_t)^2 | \mathcal{F}_{t-1} \right], \quad (14)$$

and $\mathcal{F}_t$ is the information set available at time t ,
or

$$\sigma_t^2 = \sum_{i=1}^T \left[(\Delta^d y_t - \mu_t)^2 \right] = \sum_{i=1}^T \varepsilon_t^2. \quad (15)$$

Finally, to assess the out-of-sample forecasting superiority of the ARFIMA-GARCH model with exogenous variables, we use the popular mean average percentage error (MAPE) and root mean squared forecasting error (RMSFE) criteria for an horizon of twelve (12) days, i.e. $h = 1, \dots, 12$. The out-of-sample forecasting has been conducted using both an expanding rolling windows as well as a fixed rolling windows approach.

3 Empirical analysis

3.1 Data and variables

All the data related to the COVID-19 pandemic were downloaded in daily format from the Johns Hopkins University database. In our analysis, we chose one important epicenter for Europe, namely the country of Italy. The respective stock market index was downloaded in daily format from the Yahoo finance webpage. As the confirmed cases of the COVID-19 victims are represented by a cumulative summation time series, the effect of the weekends—during which no data for stocks are available—is represented by Monday's stock behavior. Based on this fact, we use only the common dates for both time series. Table 1 shows the descriptive statistics of the time series.

Table 1 Descriptive statistics

Variable	Mean	Standard deviation	Min	Max
COVID_Italy	5671.389	11,309.57337	0	41,035
MIB_Italy	21,821.59	3622.89	14,455.23	25,477.55

Table 2 Geweke/Porter-Hudak (GPH 1983) test for long memory fractional integration) test

Stock Index_Country	Est d	Standard error	T (Ho: $d=0$)	$P> t $	Z (Ho: $d=0$)	$P> z $
MIB_Italy	131.923	0.1241	106.316	0.000	29.777	0.003

Table 3 Baseline and alternative models using information criteria

Information criterion	MIB_ITA	
	Baseline model	Alternative model
Akaike	−448.797	−508.842
Bayes	−414.437	−464.665
Shibata	−461.177	−527.881
Hannan-Quinn	−439.681	−497.122

3.2 Empirical results

We begin by testing for the long memory properties in our time series, using the Geweke/Porter-Hudak test, for establishing the baseline model for the stock market index. The test for long memory is an important aspect in the econometric framework of time series since, in financial econometrics, there are time series that exhibit long memory, in the sense that two points of the time series are dependent. The econometric question here is how this dependence varies depending on the time distance of these two points. In other words, if a time series is fractionally integrated then the statistical dependence between any two point of the time series decreases using power decay in their distance and not exponential that is the case when a time series exhibits a unit root behavior (Hassler 2018).

According to Table 2, all the time series exhibit long-term memory, which means that we have to use an ARFIMA model, instead of ARIMA.

Next, we proceed to the implementation of the ARFIMA-GARCH model with and without exogenous variables. The use of a GARCH specification in our analysis is done to coherently model the error term structure of our model by correcting for heteroskedasticity. For the MIB stock market index the baseline specification is the ARFIMA (1, 1, 0)-GARCH (1, 1). In this way, based on common practice in financial econometrics, we set the baseline model structure that could be used to coherently describe the evolution of the Italian stock market index.

The superiority of the alternative model that includes the COVID-19 cases as exogenous, over the baseline model without exogenous, is confirmed by the various information criteria employed in Table 3. The information criteria are used to evaluate the performance of each competing model.

Next, Table 4 shows the alternative optimal model for the Italian stock price index, based on relevant information criteria. According to these results, we can infer that the COVID-19 coefficient (κ) in mean of the GARCH model is negative and statistically significant. This means that COVID-19 has a negative impact on the stock market, which implies that the coronavirus spread affects statistically

Table 4 ARFIMA (2, 1, 0)-GARCH (1, 1) with exogenous variables

Parameters	MIB_ITA	
	Estimate	<i>t</i> value
μ	10.1*	2002.000
φ_1	0.968*	8.82
φ_2	−0.493	−1.280
Arfima <i>d</i>	0.5	0.854
κ	−0.02*	−8.25
ω	2.22×10^{-16}	4.39×10^{-11}
α_1	10^{-6}	10–6
β_1	0.908*	31.9
γ_1	1.59×10^{-5} *	5.42×10^4

*Denotes statistical significance at the 5% level or higher

significantly the stock market price index in a negative way. Moreover, the coefficient of the volatility of COVID-19 (γ_1) is positive and statistically significant, indicating that the volatility of the recent pandemic increased the volatility of the stock price index.

Next, we assess whether a non-linear GARCH specification should be considered for capturing the volatility of the stock market index under scrutiny. The use of a linear GARCH model is justified due to the fact that in the alternative non-linear case (Table 5), the coefficient of the volatility of COVID-19, is not statistically significant, as indicated by the *t*-stat.

Table 6 presents the MAPE and RMSFE results for the baseline and alternative model, respectively. The results indicate that the alternative model is better in terms of its forecasting ability than the baseline, which means that the presence of the information captured through the COVID-19 time series, is important for the forecasting of the stock price index time series.

Table 5 Non-linear ARFIMA (2, 1, 0)-GARCH (1, 1) with exogenous variables

Parameters	MIB	
	Estimate	<i>t</i> value
<i>M</i>	24.9*	$3.16 \times 10^{+3}$
φ_1	4.06×10^{-2} *	$3.13 \times 10^{+3}$
φ_2	3.99×10^{-2} *	$3.13 \times 10^{+3}$
Arfima <i>d</i>	0.32*	$3.13 \times 10^{+3}$
<i>K</i>	−1.87*	$-2.75 \times 10^{+3}$
ω	8.89×10^{-7} *	2.79
α_1	1.04×10^{-2} *	$3.18 \times 10^{+3}$
β_1	0.70*	$2.78 \times 10^{+3}$
γ_1	5.68×10^{-8}	0.18

*Denotes statistical significance at the 5% level or higher

Table 6 MAPE and RMFSE: baseline and alternative models

Horizon (days)	MIB_ITA			
	Baseline model		Alternative model	
	MAPE	RMFSE	MAPE	RMFSE
$h = 1$	0.130	0.004	0.183	0.005
$h = 2$	2.253	0.022	2.199	0.021
$h = 3$	1.656	0.021	1.587	0.021
$h = 4$	1.419	0.033	1.348	0.033
$h = 5$	1.410	0.050	1.333	0.050
$h = 6$	1.384	0.068	1.302	0.067
$h = 7$	1.226	0.063	1.148	0.062
$h = 8$	3.050	0.060	2.861	0.059
$h = 9$	2.860	0.071	2.599	0.070
$h = 10$	2.766	0.070	2.447	0.068
$h = 11$	2.783	0.068	2.410	0.065
$h = 12$	2.568	0.065	2.159	0.062

4 Conclusion

In this paper, we investigated the impact of the recent COVID-19 pandemic on the Italian stock market volatility. More precisely, early evidence regarding the impact of COVID-19 on the Italian stock market index is found to be statistically significant. In fact, based on our findings, we witness a decreasing impact of COVID-19 on the Italian stock market index, and an increasing impact on its volatility, where both effects are statistically significant.

Also, based on its forecasting ability, the alternative model, which incorporates the information induced by the COVID-19 cases, is better in every forecasting horizon, except for the case of the first horizon. This means that the COVID-19 time series contributes with statistically significant information in the modeling of the stock market index as well as its volatility, and also increases the forecasting ability of the model.

Based on our findings, the pandemic of COVID-19 played a negative role for the Italian stock market index. On one hand, Italy's stock market index witnessed an abrupt shock due to the pandemic, despite the fact that the COVID-19 pandemic per se is exogenous to the operations of the financial market. Nonetheless, the financial market of Italy, had a negative reaction to the pandemic and the COVID-19 cases, due to the pandemic. This, in turn, gives credence to the view that negative news play a major role in investor sentiment, in the sense that investors, in the Italian stock market, identified the external shock as a primary factor that could lead daily operations of firms and industries to a halt, diminishing at the same time their expected annual profitability. As a result, investors tried to protect their portfolios' profitability by turning to other commodities and assets vis-a-vis the stock market. This led the Italian stock market to experience high

volatility that is captured in the analysis by the GARCH specification and the statistically significant effect of COVID-19 cases on the volatility of the market.

Our research has certain policy implications. To begin with, policy actors should try to eliminate the negative impact of news like COVID-19 daily cases by boosting and backing up the overall activity with stimulus packages, in a more timely manner. In other words, the EU announced the stimulus package of the entire EMU on the 23rd of April, more than a month after the declaration of COVID-19 virus as a pandemic. This delay, forced a number of EMU stock exchange markets to face drops that accounted for almost 20% of their overall stock exchange price index. In addition, policy actors should make publicly available the “whole picture” about the pandemic, by reporting not only new cases and deaths but also the number of tests conducted, the positivity rate, the number of hospitalized cases, etc. In this way, a high reported number of new cases would not have the same effect, since this high number could be the result of more tests conducted, with the same or even diminishing positivity rate.

Clearly, as a future research, a multivariate GARCH model with many countries' stock market indices with exogenous variables would be of great interest, to capture the various spillover effects of the various stock prices, and also the multivariate effect of the COVID-19 pandemic on global stock markets.

Acknowledgements The authors would like to thank the anonymous referees and the Guest Editor of this Journal, Professor Dr. Theodore Mariolis, for their helpful comments and suggestions.

Funding No funds, Grants, or other support was received.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

- Abdalla AZS (2012) Modelling stock returns volatility: empirical evidence from Saudi stock exchange. *Int Res J Financ Econ* 85:166–179
- Akhtaruzzaman M, Boubaker S, Sensoy A (2020) Financial contagion during COVID–19 crisis. *Financ Res Lett*. <https://doi.org/10.1016/j.frl.2020.101604>
- Albuquerque R, Koskinen Y, Yang S, Zhang C (2020) Resiliency of environmental and social stocks: an analysis of the exogenous COVID-19 market crash. *Rev Corp Financ Stud* 9:593–621
- Ashraf BN (2020) Economic impact of government interventions during the COVID-19 pandemic: international evidence from financial markets. *J Behav Exp Financ* 27:1–9
- Baillie RT (1996) Long memory processes and fractional integration in econometrics. *J Econom* 73:5–59
- Baker SN, Bloom S, Davis K, Kost M, Sammon TV (2020) The unprecedented stock market impact of COVID-19. *Rev Asset Pricing Stud* 10(4):742–758
- Bekaert G, Harvey CR (1997) Emerging equity market volatility. *J Financ Econ* 43:29–77
- Beran J (1994) Statistics for long-memory processes. Chapman & Hall/CRC, Boca Raton
- Bollerslev T (1986) Generalized autoregressive conditional heteroskedasticity. *J Econom* 31(3):307–327
- Cheng IH (2020) Volatility markets underreacted to the early stages of the COVID-19 pandemic. *Rev Asset Pricing Stud* 10(2020):635–668

- Daglis T, Konstantakis KN, Michaelides PG, Papadakis TE (2020) The forecasting ability of solar and space weather data on NASDAQ's finance sector price index volatility. *Rese Int Bus Financ* 52(C):101147
- Donadelli M, Kizys R, Riedel M (2017) Dangerous infectious diseases: bad news for main street, good news for wall street. *J Financ Mark* 35:84–103
- Gallego V, Nishiura H, Sah R, Rodriguez-Morales AJ (2020) The COVID-19 outbreak and implications for the Tokyo 2020 Summer Olympic Games. *Travel Med Infect Dis*. <https://doi.org/10.1016/j.tmaid.2020.101604> (Epub ahead of print)
- Geweke J, Porter-Hudak S (1983) The estimation and application of long memory time series models. *J Time Ser Anal* 4:221–238
- Gormsen NJ, Koijen RSJ (2020) Coronavirus: impact on stock prices and growth expectations. *Rev Asset Pricing Stud* 10:574–597
- Haroon O, Rizvi SAR (2020) COVID-19: media coverage and financial markets behavior—a sectoral inquiry. *J Behav Exp Financ* 2020:27. <https://doi.org/10.1016/j.jbef.2020.100343>
- Hassler U (2018) Time series analysis with long memory in view. Wiley (ISBN: 978-1-119-47040-3)
- Hoshikawa T, Yoshimi T (2021) The effect of the COVID-19 pandemic on South Korea's stock market and exchange rate. *Dev Econ* 59:206–222. <https://doi.org/10.1111/deve.12276>
- Just M, Echaust K (2020) Stock market returns, volatility, correlation and liquidity during the COVID-19 crisis: evidence from the Markov switching approach. *Financ Res Lett*. <https://doi.org/10.1016/j.frl.2020.101775>
- Lee J-W, McKibbin W (2004) Estimating the global economic costs of SARS. In: Knobler S, Mahmoud A, Lemon S, Mack A, Sivitz L, Oberholtzer K (eds) *Learning from SARS: preparing for the next outbreak*. The National Academies Press, Washington DC
- Liu Y, Gayle AA, Wilder-Smith A, Rocklöv J. The reproductive number of COVID-19 is higher compared to SARS coronavirus. *J Travel Med*. 2020 Mar 13; 27(2):taaa021. <https://doi.org/10.1093/jtm/taaa021>. PMID: 32052846; PMCID: PMC7074654
- Lives. <https://www.bbc.com/news/world-asia-51836898>
- McKibbin W, Fernando R (2020) The global macroeconomic impacts of COVID-19: seven scenarios. Working paper, CAMA-Centre for Applied Macroeconomic Analysis, pp 1–43
- Meltzer MI, Cox NJ et al (1999) The economic impact of pandemic influenza in the United States: priorities for intervention. *Emerg Infect Dis* 5(5):659–671
- Palma W (2007) Long-memory time series: theory and methods. Wiley, Hoboken
- Park JY, Han H (2012) ARCH/GARCH with persistent covariate: asymptotic theory of MLE. *J Econom* 167:95–112
- Ramelli S, Wagner AF (2020) Feverish stock price reactions to COVID-19. *Rev Corp Financ Stud* 9:622–655
- Samiev S (2013) GARCH (1, 1) with exogenous covariate for EUR/SEK exchange rate volatility on the effects of global volatility shock on volatility. Master Thesis, 4-5. <http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A676106&dsid=1186>
- Scheicher M (2001) The comovements of stock markets in Hungary, Poland and The Czech Republic. *Int J Financ Econ* 6:27–39
- Sohrabia C, Alsafib Z, O'Neill N, Khanb M, Kerwanc A, Al-Jabirc A, Iosifidisa C, Aghad R (2020) World Health Organization declares global emergency: a review of the 2019 novel coronavirus (COVID-19). *Int J Surg* 76:71–76
- Syriopoulos T (2007) Dynamic linkages between emerging European and developed stock markets: has the EMU any impact? *Int Rev Financ Anal* 16:41–60
- The White House (2020) Proclamation on suspension of entry as immigrants and nonimmigrants of persons who pose a risk of transmitting 2019 novel coronavirus. <https://www.whitehouse.gov/presidential-actions/proclamation-suspension-entry-immigrants-nonimmigrants-persons-pose-risktransmitting-2019-novel-coronavirus/>
- WHO-World Health Organization (2020) Coronavirus disease 2019 (COVID-19). Situation Report—51
- Wilder-Smith A, Chiew CJ, Lee VJ (2020) Can we contain the COVID-19 outbreak with the same measures as for SARS? *Lancet Infect Dis*. [https://doi.org/10.1016/S1473-3099\(20\)30129-8](https://doi.org/10.1016/S1473-3099(20)30129-8)