Volatility dynamics of the Tunisian stock market before and during the COVID-19 outbreak: Evidence from the GARCH family models

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Abstract
The aim of this article is to choose the appropriate GARCH model to analyse the volatility dynamics of the Tunisian sectorial stock market indices during the COVID-19 outbreak period. We explore the optimal conditional heteroscedasticity model with regards to goodness-of-fit to these sectorial indices. In particular, it proposes four models (EGARCH, FIGARCH, FIEGARCH and TGARCH) to measure asymmetric and persistence volatility. Our findings point to three interesting results. First, following the COVID-19 outbreak, volatility is more persistent in all series. Second, the results show that building constructs materials, construction and food and beverage sector return volatilities have an insignificant asymmetric effect while consumer service, financials and distribution, industrials, basic materials and banks sector return volatilities have relatively high positive and significant asymmetric effect compared with those during the pre-COVID-19 period. Finally, the findings show that financial services, automobile and parts, insurance and TUNINDEX20 sectors have insignificant leverage effect. Our results can thus be useful to investors when accounting for future volatility and implementing hedging strategies under COVID-19 crisis.

KEYWORDS
COVID-19 outbreak, GARCH models, Tunisian sectorial stock market indices

1 | INTRODUCTION

On 11 March 2020, the COVID-19 epidemic was declared a pandemic by the WHO, which asked for essential protective measures to prevent saturation of the intensive care services and to reinforce preventive hygiene. This global pandemic is causing serial cancellations of sporting and cultural events all over the planet, the implementation by many countries of containment measures to slow the formation of new outbreaks of contagion, the closing of borders of many countries, and a stock market crash due to the uncertainties and fears that it poses for the world economy. Indeed, this pandemic which started in China has affected private consumption spending (transport, leisure and retail) and significantly reduced manufacturing activities. Changes in consumer behaviour, as well as social distancing, have necessitated an increase in online purchasing. This later has benefitted the big players but harmed small and medium-sized enterprises, which were not exploiting service delivery and web-based product (Ibn-Mohammed et al., 2021). Due to the interconnectedness of markets and the importance of China as the ‘factory of the world’, this slowdown has inevitably led to a revision of global growth forecasts.
By using wavelet coherence analysis to estimate the interdependence and causality between the EPU and 11 sectors of the S&P 500 index, Choi (2020) investigated the impact of economic uncertainty due to the COVID-19 pandemic on the industrial economy in the United States. They found that the 2020 global pandemic has a substantial impact on all sectors of the US stock market. Furthermore, its influence on the industrial economy is larger than that of the global financial crisis. Gunay and Kurtulmus (2020) investigated the impact of the COVID-19 on the US service sector. They suggested that the pandemic affected mainly the entertainment and airline industries, hotel industry, led by small-market-cap companies. However, there is no negative impact on the restaurant industry. The results indicated also that the global pandemic created a growth opportunity for technology-intensive services. In the same line, Chen, Demir, García-Gómez, and Zaremba (2020) analysed the impact of government restrictions on stock returns of US travel and leisure companies during the 2020 global pandemic. They demonstrate that stock prices of travel and leisure firms with a smaller size and higher cash reserves are more resilient to the Coronavirus related government restrictions. In addition, Baek et al. (2020) indicated that COVID-19 has had a significant impact on US stock market volatility. The findings indicate that both negative and positive 2020 global pandemic information are significant and negative news is more. They observed also significant increases in total risk across all industries, while changes in systematic risk vary across industries. They document decreases in systematic risk for aggressive industries, but significant increases in systematic risk for defensive industries. In addition, changes in volatility are less sensitive to economic indicators than COVID-19 news.

Mirza, Rahata, Naqvi, Kumail, and Rizvi (2020) investigated the impact of COVID-19 on the solvency profile of 12,387 non-financial listed companies in the 15 European member states. Their results show that the retail sector, mining and manufacturing are most vulnerable to a reduction in sales revenues and a decline in market capitalization. Sherif (2020) explored the impact of the rapid spread of Coronavirus on the Shariah-compliant UK Dow Jones market index. The reached findings show that the stock returns of the information technology sector performed significantly better than the market. However, stock returns of the consumer discretionary sector, which includes beverages, consumer services tourism and leisure as well as transportation, are significantly lower than the global market returns during the COVID-19 outbreak.

Most of the research on the impact of COVID-19 on different economic sectors has focused on developed countries. However, a small number of studies have investigated the impact of the global pandemic on underdeveloped economies. Akrofi and Antwi (2020) studied energy sector government interventions in response to COVID-19 in Africa. They found that the majority of responses in all African countries were in the form of aid packages, monetary/fiscal incentives and economic stimulus packages/bills to boost liquidity in their economies. Jeribi and Snene Manzli (2020) studied the behaviour of the Tunisian stock market returns during the COVID-19 outbreak. They found that the growth rate of the Coronavirus confirmed cases and deaths harm all the sectorial stock market indices. On 30 April 2020, more than 3.2 million cases of COVID-19 have been detected worldwide, a disease that has killed more than 230,000 people since the start of the pandemic, including more than 70,000 in the United States. The COVID-19 pandemic has been officially developing in Tunisia since 2 March 2020. Since the appearance of the coronavirus in Tunisia for the first time, the health situation has become increasingly critical. Indeed, the number of infected people is experiencing remarkable growth every day, knowing that the government and medical staff are making great efforts to deal with this unexpected health crisis. As of 30 April, 980 cases of contamination have been confirmed as well as 39 deaths, an average of 80 cases and 3 deaths per million inhabitants. The reduced number of cases observed in Tunisia is due to the efficiency of the medical teams and the responsiveness of the government, which closed the borders on 18 March as well as the curfew from 18 March, from 6 p.m. to 6 a.m., total containment, and the prohibition of all travel between built-up areas. From 4 May begins the first of three phases of progressive containment decreed by the government, which plans to restart the economy gradually between 4 May and 14 June, and this is according to the evolution of the pandemic in the country.

The global COVID-19 pandemic, and in particular the unprecedented measures taken by the Tunisian government to contain it, has created a strong downward trend in the Tunindex, which has accelerated (trend) following the transition to the second level of containment and the closure of maritime borders (13 March 2020). Between 13 and 17 March 2020, the Tunindex lost 10.2%, falling by 15.11% between 2 and 17 March 2020. Over the whole of the first quarter of 2020, the index recorded a decrease of −8.97% and the TUNBANK values fell by 9.76%. At first, this downward trend was general and did not spare any sector. The banking sector, which represents 41.4% of the total capitalization of the Tunis stock exchange and 52.6% of the Tunindex, seems to be the more influenced sector. The stock market plunged again into the red following the call of the central bank of Tunisia to the
banks to suspend any measure of the distribution of dividends for the 2019 financial year and to refrain from carrying out any repurchase transaction of their own shares.

A similar scenario was experienced during the Tunisian revolution in 2011, namely curfew, economic uncertainty and a downward trend in the Tunindex. Kaddour and Zmami (2014) and Jeribi, Fakhfekh, and Jarboui (2015) empirically studied the impact of political uncertainty during the Tunisian revolution on the behaviour of the stocks. Using an event study analysis, Kaddour and Zmami (2014) observed a decrease in the performance of the banking sector and an increase in the exchange rate volatility after the Tunisian revolution. Applying the fractionally integrated exponential GARCH, they found that shock impact on construction, raw materials and financial service index volatility returns is permanent during the revolution period and transitory for other indices. Applying the same model as Fakhfekh, Hachicha, Jawadi, Selmi, and Idi Cheffou (2016), Jeribi et al. (2015) suggested that the shock impact throughout the Jasmine revolution period on industries, construction, financial services, consumer services financial companies indices’ sectorial and the TUNINDEX return volatilities is permanent, while its persistence on the other indices is transitory.

Given the success of the containment policy in Tunisia, there is a need for many researches in order to examine the effects of the COVID-19 pandemic to better analyse and understand the relationship between economic uncertainty and stock market volatility.

Moreover, long memory properties and asymmetric effects stand also as stylized facts, likely to bring about major financial outcomes. In general, a time series is considered to exhibit a long memory and asymmetric behaviour, once its relating autocorrelation function, proves to be non-integrable. In fact, the main outcome associated with long memory lies in the nonlinear dependence it reflects throughout the first and second moments (Elder and Serletis, 2008). Besides, a high long-memory related coefficient proves to reveal that the asset displays long positive or negative strays from the equilibrium. As a result, such a commodity is no longer representing a good hedge or a safe haven, due to its failure in providing an effective refuge against adverse market conditions.

Volatility is essential to the functioning of financial markets. It is considered a barometer of uncertainty surrounding investments in financial assets. Investors, financial industry regulators as well as policymakers are very interested in volatility. Most of the research on the impact of the COVID-19 has focused on developed countries. Few studies have established a link between the COVID-19 pandemic and under developed financial market volatility. In this context, the present study is designed to select the best model or set of models useful for effectively modelling volatility relating to the Tunisian sectorial indices. By using four GARCH specifications, namely FIGARCH, FIEGARCH, EGARCH and TGARCH models, we analysed the effect of the COVID-19 outbreak on these sectorial indices. As the COVID-19 is new and emerging in the whole world, the article’s contribution consists to investigate which of both asymmetric and long-memory conditional heteroscedasticity models proves to stand better fit to describe the Tunisian sectorial stock market return attached volatilities before and during the COVID-19 virus outbreak.

The remainder of this article is organized as follows. Section 2 serves to discuss our applied econometric methodology. Section 3 is devoted to highlight the relevant data and empirical findings. Section 4 depicts the article’s relevant conclusions.

2 | ECONOMETRIC METHODOLOGY

In the basic GARCH model, since only squared residuals $\varepsilon_{t-1}^2$ enter the equation, the signs of the residuals or shocks have no effects on conditional volatility. However, a stylized fact of financial volatility is that bad news (negative shocks) tends to have a larger impact on volatility than good news (positive shocks). Black (1976) attributed this effect to the fact that bad news tends to drive down the stock price, thus increasing the leverage (i.e., the debt–equity ratio) of the stock and causing the stock to be more volatile. Based on this conjecture, the asymmetric news impact is usually referred to as the leverage effect. This subsection focuses on the EGARCH, TGARCH, FIGARCH and FIEGARCH models.

2.1 | EGARCH model

Nelson (1991) proposed the following exponential GARCH (EGARCH) model to allow for leverage effects:

$$h_t = a_0 + \sum_{i=1}^{p} a_i \frac{|\varepsilon_{t-i}| + \gamma_i \varepsilon_{t-i}}{\sigma_{t-i}} + \sum_{j=1}^{q} b_j h_{t-j},$$  \hspace{1cm} (1)

where $h_t = \log \sigma_t^2$ or $\sigma_t^2 = e^{ht}$. Note that when $\varepsilon_{t-i}$ is positive or there is ‘good news’, the total effect of $\varepsilon_{t-i}$ is $(1 + \gamma_i)|\varepsilon_{t-i}|$; in contrast, when $\varepsilon_{t-i}$ is negative or there is ‘bad news’, the total effect of $\varepsilon_{t-i}$ is $(1 - \gamma_i)|\varepsilon_{t-i}|$. Bad news can have a larger impact on volatility, and the value of $\gamma_i$ would be expected to be negative.
2.2 | TGARCH model

Another GARCH variant that is capable of modelling leverage effects is the threshold GARCH (TGARCH) model, which has the following form:

\[ \sigma_t^2 = a_0 + \sum_{i=1}^{p} a_i \epsilon_{t-i}^2 + \sum_{i=1}^{q} \gamma_i S_{t-i} \epsilon_{t-i}^2 + \sum_{j=1}^{q} b_j \sigma_{t-j}^2, \]  
(2)

where \( S_{t-i} = \begin{cases} 1 & \text{if } \epsilon_{t-i} < 0 \\ 0 & \text{if } \epsilon_{t-i} \geq 0 \end{cases} \).

That is, depending on whether \( \epsilon_{t-i} \) is above or below the threshold value of zero, \( \epsilon_{t-i}^2 \) has different effects on the conditional variance \( \sigma_t^2 \): when \( \epsilon_{t-i} \) is positive, the total effects are given by \( a_i \epsilon_{t-i}^2 \); when \( \epsilon_{t-i} \) is negative, the total effects are given by \( (a_i + \gamma_i) \epsilon_{t-i}^2 \). So one would expect \( \gamma_i \) to be positive for bad news to have larger impacts. This model is also known as the GJR model because Glosten, Jagannathan, and RunkleD (1993) proposed essentially the same model.

2.3 | FIGARCH model

The basic GARCH(1, 1) model can be written as an ARMA(1, 1) model in terms of squared residuals. In the same spirit, for the GARCH(p, q) model:

\[ \sigma_t^2 = a_0 + \sum_{i=1}^{p} a_i \epsilon_{t-i}^2 + \sum_{j=1}^{q} b_j \sigma_{t-j}^2, \]  
(3)

Easily shows that it can be rewritten as follows:

\[ \phi(L) \epsilon_t^2 = a_0 + b(L) u_t, \]  
(4)

where \( u_t = \epsilon_t^2 - \sigma_t^2 \),

\[ \phi(L) = 1 - \phi_1 L - \phi_2 L^2 - \cdots - \phi_m L^m, \]

\[ b(L) = 1 - b_1 L - b_2 L^2 - \cdots - b_q L^q, \]

with \( m = \max(p, q) \) and \( \phi_i = a_i + b_i \). Obviously, Equation (4) represents an ARMA\((m, q)\) process in terms of squared residuals \( \epsilon_t^2 \) with \( u_t \) being a MDS disturbance term.

The high persistence in GARCH models suggests that the polynomial \( \phi(z) = 0 \) may have a unit root, in which case the GARCH model becomes the integrated GARCH (IGARCH) model. See Nelson (1991) for which the unconditional variance does not exist. To allow for high persistence and long memory in the conditional variance while avoiding the complications of IGARCH models, extend the ARMA\((m, q)\) process in Equation (4) to a FARIMA\((m, d, q)\) process as follows:

\[ \phi(L)(1-L)^d \epsilon_t^2 = a_0 + [1-b(L)] u_t, \]  
(5)

with \( \phi(L) = [1-a(L)-b(L)](1-L)^{-1} \) where all the roots of \( \phi(z) = 0 \) and \( b(z) = 0 \) lie outside the unit circle. When \( d = 0 \), this reduces to the usual GARCH model; when \( d = 1 \), this becomes the IGARCH model; when \( 0 < d < 1 \), the fractionally differenced squared residuals, \((1-L)^d \epsilon_t^2\), follow a stationary ARMA\((m, q)\) process. The above FARIMA process for \( \epsilon_t^2 \) can be rewritten in terms of the conditional variance \( \sigma_t^2 \):

\[ b(L) \sigma_t^2 = a + [b(L) - \phi(L)(1-L)^d] \epsilon_t^2. \]  
(6)

Baillie, Bollerslev, and Mikkelsen (1996) referred to the above model as the fractionally integrated GARCH, or FIGARCH\((m, d, q)\) model. When \( 0 < d < 1 \), the coefficients in \( \phi(L) \) and \( b(L) \) capture the short run dynamics of volatility, while the fractional difference parameter \( d \) models the long-run characteristics of volatility.

2.4 | FIEGARCH model

The FIGARCH model directly extends the ARMA representation of squared residuals, which results from the GARCH model to a fractionally integrated model. However, to guarantee that a general FIGARCH model is stationary and the conditional variance \( \sigma_t^2 \) is always positive, usually complicated and intractable restrictions have to be imposed on the model coefficients.

Noting that an EGARCH model can be represented as an ARMA process in terms of the logarithm of conditional variance and thus always guarantees that the conditional variance is positive, Bollerslev and Mikkelsen (1996) proposed the following fractionally integrated EGARCH (FIEGARCH) model:

\[ \phi(L)(1-L)^d \ln \sigma_t^2 = a + \sum_{j=1}^{q} \left( b_j |x_{t-j}| + \gamma_j x_{t-j} \right), \]  
(7)

where \( \phi(L) \) is defined as earlier for the FIGARCH model, \( \gamma_j \neq 0 \) allows the existence of leverage effects, and \( x_t \) is the standardized residual:

\[ x_t = \frac{\epsilon_t}{\sigma_t}. \]  
(8)

Bollerslev and Mikkelsen (1996) showed that the FIEGARCH model is stationary if \( 0 < d < 1 \).
3 | DATA AND RESULTS

3.1 | Data and descriptive statistics

We use the adjusted closing price data of 12 sectorial indices (financial services; consumer services; industrials; financials; distribution; construction; building construct materials; basic materials; banks; automobile and parts; insurance; food and beverage) and the benchmark TUNINDEX20 index listed in the TSE. The database was collected from Datastream base and the TSE website for the period from 4 January 2016 to 30 April 2020 with a

FIGURE 1  Evolution in price returns [Colour figure can be viewed at wileyonlinelibrary.com]
| TABLE 1 | Descriptive statistics |
|---|---|
| | Mean | SD | Skew. | Kurt. | LM | Q(16) | Q2(16) | RS/mod | J-Bera | Obs. |
| Whole period | SERF | -0.00016 | 0.0057 | 0.092 | 4.104 | 50.79** | 14.99 | 50.04*** | 1.78* | 56.369*** | 1,080 |
| | SAC | -0.00026 | 0.0060 | -0.138 | 4.296 | 141.89*** | 43.81*** | 174.21*** | 2.03*** | 79.051*** | 1,080 |
| | IND | -0.00013 | 0.0092 | 0.159 | 3.856 | 164.51*** | 86.54*** | 273.37*** | 2.11*** | 37.539*** | 1,080 |
| | FIN | 0.00018 | 0.0059 | -0.996 | 14.093 | 231.64*** | 81.92*** | 268.32*** | 1.89*** | 5716.48*** | 1,080 |
| | DIS | -0.00026 | 0.0063 | -0.155 | 4.464 | 148.43*** | 40.67*** | 188.35*** | 2.11*** | 100.769*** | 1,080 |
| | CONST | 0.00038 | 0.0077 | -0.114 | 7.993 | 220.06*** | 64.49*** | 342.63*** | 2.38*** | 1124.27*** | 1,080 |
| | BAT | -0.00043 | 0.0125 | 0.278 | 3.590 | 205.94*** | 95.70*** | 458.05*** | 1.44*** | 29.575*** | 1,080 |
| | BASE | 0.00034 | 0.0090 | -0.216 | 5.733 | 218.57*** | 55.44*** | 306.81*** | 2.77*** | 344.558*** | 1,080 |
| | BANK | 0.00021 | 0.0064 | -0.948 | 13.852 | 226.29*** | 77.85*** | 260.49*** | 1.86*** | 5460.92*** | 1,080 |
| | AUTO | -0.00018 | 0.0134 | 0.275 | 3.997 | 183.99*** | 25.08* | 322.24*** | 1.71* | 58.320*** | 1,080 |
| | INS | 0.00006 | 0.0083 | 0.162 | 4.261 | 102.19*** | 41.14*** | 94.03*** | 1.76* | 76.353*** | 1,080 |
| | ALIM | 0.00046 | 0.0086 | 0.198 | 7.163 | 172.45*** | 53.88*** | 285.13*** | 2.55*** | 786.865*** | 1,080 |
| | TUN20 | 0.00021 | 0.0057 | -1.427 | 15.046 | 399.36*** | 110.47*** | 508.77*** | 1.68*** | 6895.89*** | 1,080 |
| Pre-COVID period | SERF | -0.00014 | 0.0056 | 0.087 | 4.232 | 58.022*** | 20.03 | 51.86*** | 1.66* | 64.392*** | 998 |
| | SAC | -0.00022 | 0.0058 | 0.049 | 3.549 | 112.54*** | 38.15*** | 130.85*** | 1.59* | 12.928*** | 998 |
| | IND | 0.00009 | 0.0091 | 0.331 | 3.663 | 114.59*** | 68.31*** | 178.28*** | 1.71* | 36.493*** | 998 |
| | FIN | 0.00033 | 0.0055 | -0.482 | 13.521 | 156.58*** | 59.67*** | 167.61*** | 2.51*** | 4641.25*** | 998 |
| | DIS | -0.00022 | 0.0060 | 0.039 | 3.680 | 122.59*** | 39.37*** | 147.37*** | 1.64* | 19.461*** | 998 |
| | CONST | 0.00050 | 0.0071 | 0.616 | 5.802 | 107.63*** | 28.33** | 187.71*** | 2.04*** | 389.542*** | 998 |
| | BAT | -0.00029 | 0.0126 | 0.304 | 3.587 | 184.67*** | 89.59*** | 419.32*** | 1.47* | 29.681*** | 998 |
| | BASE | 0.00074 | 0.0086 | 0.206 | 4.535 | 123.82*** | 26.74*** | 223.94*** | 2.83*** | 105.028*** | 998 |
| | BANK | 0.00038 | 0.0060 | -0.440 | 13.336 | 153.04*** | 54.26*** | 162.90*** | 2.48*** | 4474.64*** | 998 |
| | AUTO | 0.00005 | 0.0132 | 0.416 | 3.958 | 133.09*** | 27.50* | 194.64*** | 2.03** | 66.906*** | 998 |
| | INS | 0.00015 | 0.0083 | 0.189 | 4.369 | 104.72*** | 39.12*** | 100.90*** | 1.93* | 83.855*** | 998 |
| | ALIM | 0.00054 | 0.0080 | 0.711 | 6.156 | 113.18*** | 25.33* | 203.49*** | 2.02*** | 498.459*** | 998 |
| | TUN20 | 0.00038 | 0.0051 | -0.348 | 9.389 | 178.76*** | 47.54*** | 212.59*** | 2.25*** | 1717.38*** | 998 |
| COVID period | SERF | -0.00035 | 0.0061 | 0.154 | 2.883 | 27.192* | 20.95 | 10.49 | 1.18 | 0.370 | 82 |
| | SAC | -0.00080 | 0.0088 | -0.655 | 4.509 | 29.230* | 13.23 | 26.26* | 1.21 | 13.639*** | 82 |
| | IND | -0.00282 | 0.0110 | -0.765 | 3.629 | 34.437** | 43.81*** | 59.90*** | 1.62* | 9.342*** | 82 |
| | FIN | -0.00172 | 0.0092 | -1.812 | 8.564 | 30.225** | 39.54*** | 41.14*** | 1.52* | 150.636*** | 82 |
| | DIS | -0.00072 | 0.0092 | -0.691 | 4.634 | 28.765* | 11.28 | 28.20** | 1.17 | 15.649*** | 82 |
daily frequency for a total of 1,080 observations. We choose to start our study from 2016 because the country emerged from a period of political instability following the Tunisian revolution. In fact, there are parliamentary and presidential elections during 2014 and 2015 following the drafting of the first constitution after the revolution. It is worth noting that this period covers also the COVID-19 crisis. So, for the sake of identifying the Coronavirus impact on Tunisian stock market volatility, we consider it useful to divide the research period into two sub-periods. Dubbed the pre-COVID-19 period, the first sub-period goes from 4 January 2016 to 31 December 2019. As for the second sub-period labelled meanwhile Coronavirus period, it starts on 1 January 2020, the day on which the Coronavirus took place in mainly the whole world, and ends on 30 April 2020. Daily returns are defined by $r_t = \ln(p_t/p_{t-1})$ with $p_t$ the closing price of the stock market indices on day $t$. Figure 1 shows the return evolution over the whole period. In addition, volatility clustering is visible for the majority of assets essentially during the COVID-19 period (January–April 2020).

Descriptive statistics of these Tunisian stock market indices are summarized in Table 1. All the results are achieved by using the S-Plus 6 FinMetrics 1.0 software module. From Table 1, we notice a decrease in the average return of the entirety of the Tunisian sectorial stock market during the COVID-19 outbreak. In addition, the estimated risk through the standard deviation is relatively high for the entirety of the Tunisian stock market returns regarding those during the pre-COVID period. The Skewness values show that most of the marginal distributions are skewed to the left (the value is negative) except for the financial service sector compared to those during the pre-COVID-19 period where the majority of the marginal distributions are skewed to the right (when the value is positive). This result can be explained by the effect of the Coronavirus. The kurtosis values in our sample during the COVID-19 period are greater than 3 except for the financial service, building and construction materials sectors. The high values of the kurtosis indicate that these sectors have flattened distributions with extreme values on the tails. Higher values of the Jarque–Bera test show that the distributions are not normal for the majority of the sectorial stock market indices except for financial service, building and construction materials, automobile and parts, and insurance sectors.

The Lagrange multiplier test shows the presence of an ARCH effect in all the series of returns during all periods. The Box-Pierce Q-test strongly rejects the presence of no significant autocorrelations in the first 16 lags in the return series of all the variables except for financial service during all period and consumer service, distribution as well as insurance during the COVID-19 period.

TABLE 1 (Continued)

| Sector          | Mean | SD  | Skew. | Kurt. | $Q_t$ (16) | $Q_t$ (16) | $Q_t$ (16) | $Q_t$ (16) | $Q_t$ (16) |
|-----------------|------|-----|-------|-------|------------|------------|------------|------------|------------|
| DON             | 0.00118 | 0.0101 | -1.419 | -1.941 | 6.464 | 28.175 | 35.156 | 34.794 | 28.011 |
| BAT             | 0.00217 | 0.0110 | -0.341 | -1.245 | 2.906 | 5.552 | 29.918 | 34.979 | 28.011 |
| BASE            | 0.00455 | 0.0125 | -0.010 | -1.789 | 1.000 | 8.439 | 39.599 | 39.918 | 29.918 |
| AUTO            | 0.00079 | 0.0012 | -0.325 | -0.852 | 0.000 | 3.299 | 26.747 | 32.511 | 32.511 |
| INS             | 0.00005 | 0.0010 | -0.090 | -0.969 | 0.000 | 1.180 | 28.207 | 32.794 | 32.794 |
| TUN20           | -0.00012 | 0.0015 | -2.070 | -1.982 | 0.000 | 5.484 | 34.676 | 32.476 | 32.476 |

Note: The sector indices are: SERF, financial services; SAC, consumer services; IND, industrials; FIN, financials; DIS, distribution; CONST, construction; BAT, building and construction materials; BASE, basic materials; BANK, banks; AUTO, automobile and parts; INS, insurance; ALIM, food and beverage; TUN20, Tunisian benchmark index contains 20 companies. LM statistic is used for the ARCH test and RS/mod statistic is used to detect the long memory.

*Indicate that the estimators are significant at 1% level. **Indicate that the estimators are significant at 5% level. ***Indicate that the estimators are significant at 10% level.
while the Box-Pierce squared $Q$-test proves the presence of no significant autocorrelations in all series except for financial service and insurance sectors. As a matter of fact, the modified R/S test pertinent results reveal the existence of a long memory within the entirety of return series during all period except for financial service, consumer service, distribution as well as insurance during the COVID-19 period.

### 3.2 Tunisian stock market return volatilities results

The results of the estimation of different GARCH family during the pre-COVID-19 and COVID-19 period are presented in Tables 2 and 3, respectively. According to Table 2, the results prove that the AIC and BIC information criteria value is minimized under the AR(1)-EGARCH(1,1,1) model for financial service, industrials and building construct materials return volatility series during the pre-COVID-19 period while the volatility of other series can be explained by an AR(1)-FIEGARCH (1, d, 1) model. This result can be explained by the fact that all Tunisian sectorial indices volatilities contain an asymmetric and long memory effect. The majority of the sectorial indices present a high degree of volatility persistence (fraction: $d > 0.5$) due probably to the Tunisian revolution effect. These results are online with Jeribi et al. (2015).

Table 3 provides the results for each GARCH estimation model during the COVID-19 outbreak. Our primary focus is on the choice of the best GARCH model that describes the Tunisian stock market volatilities during the COVID-19 period. Under the two information criteria, the AR(1)-EGARCH(1,1) is the appropriate tool to describe the volatility of the building construct materials, construction and food and beverage sector returns while consumer services, financials, and distribution sectorial indices return are modulated by an AR(1)-FIEGARCH(1,1) and finally, the other sectorial indices as well as TUNINDEX20 return volatilities were described by an AR(1)-TGARCH(1,1).

Regarding the EGARCH model, the results prove that the building construct materials, construction and food and beverage sector returns volatilities are characterized by a very high persistence (>1). This strong persistence, as derived from the sum of both the ARCH and GARCH coefficients, has its explanation in the structural changes that can be introduced in the variance process due to the impact of the COVID-19 crisis. These three sectorial indices returns are characterized by a long memory effect. Indeed, we found also that these sectorial stock market return volatilities have an insignificant asymmetric effect. This result can be explained by the fact that these sectors employ a significant number of unskilled labourers who cannot work because of the curfew and total containment. The size of the service as well as building construct materials, construction and food and beverage sectors render them susceptible to potential risks, especially following the Tunisian revolution (Jeribi et al., 2015) and during the 2020 global pandemic (Jeribi & Snene Manzli, 2020). The vital importance of these sectors in spurring economic growth forced Tunisia to take measures against the recent pandemic. The negative influence in the restaurant industry caused by the Coronavirus pandemic can be explained by the Maslow (1943, 1954) hierarchy of needs theory. In addition, the substantial impact on the food and beverage sector and transportation may result from operations more conducive to Coronavirus transmission. These results are consistent with Alfaro, Chari, Greenland, and Schott (2020), Gunay and Kurtulmus (2020), Baek et al. (2020) and Mirza et al. (2020). Within this context, the Tunisian Central Bank has agreed to reduce the interest rate by 100 basis points. It was 7.84% in February 2020 and became 6.75% in March 2020. This decision improved the purchasing power of Tunisian citizens. However, it has deteriorated the profit margins of banks.

With respect to the FIEGARCH model that takes into account both of asymmetric and long memory effect, the results prove that consumer service, financials, and distribution sector return volatilities have a high degree of persistence compared between 0.778 and 0.972. However, these sectorial stock market indices have relatively high positive and significant asymmetric effects compared with those during the pre-COVID-19 period. This result can be explained by the fact that these sectorial stock market indices are not dominated by uninformed investors but instead by informed investors. In addition, the changes in Tunisian consumer behaviour, as well as social distancing, have necessitated an increase in online purchasing. The 2020 pandemic has benefitted the big players but harmed small and medium-sized enterprises which represent more than 90% of Tunisian companies, who were not exploiting service delivery and web-based product.

Finally, regarding the TGARCH model that takes into account the leverage effect, the achieved findings show that industrials, basic materials and banks sector indices return volatilities have a positive and significant coefficient of leverage effect while the financial services, automobile and parts, insurance and TUNINDEX20 sectors have insignificant leverage effect. This result can be explained by the fact that the positive shocks increase the volatility by high than negative shocks which are in stark contrast to the positive coefficient and that these stock
| Model        | Parameter | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 | Value 6 |
|-------------|-----------|---------|---------|---------|---------|---------|---------|
| FIGARCH     | C         | -0.00025 | -0.0283 | 4.60x10^{-5} | 0.7000*** | 0.4000*** | —       | 0.5000** | -7,469.06 | -7,439.63 |
|             | SAC       | -0.00024 | 0.0475  | 7.21x10^{-6} | 0.7000*** | 0.4000*** | —       | 0.5000*  | -7,381.15 | -7,351.71 |
|             | IND       | 0.00005  | 0.1171*** | 0.000001* | 0.7000*** | 0.4000*** | —       | 0.5000** | -6,594.66 | -6,565.23 |
|             | FIN       | 0.00004  | 0.1383*** | 0.000002*** | 0.7000*** | 0.4000*** | —       | 0.5000*** | -7,777.88 | -7,748.45 |
|             | DIS       | -0.00021 | 0.0506  | 4.80x10^{-6} | 0.7000*** | 0.4000*** | —       | 0.5000** | -7,378.35 | -7,348.92 |
|             | CONST     | 0.00029  | 0.0474  | 4.82x10^{-6} | 0.7000*** | 0.4000*** | —       | 0.5000** | -7,147.46 | -7,118.02 |
|             | BAT       | -0.00023 | 0.1107*** | 0.00002*** | 0.7000*** | 0.4000*** | —       | 0.5000*** | -5,972.90 | -5,943.46 |
|             | BASE      | 0.00055** | 0.0517  | 3.93x10^{-5} | 0.7000*** | 0.4000*** | —       | 0.5000*** | -6,790.45 | -6,761.01 |
|             | BANK      | 0.00004  | 0.1294  | 2.86x10^{-6} | 0.7000*** | 0.4000*** | —       | 0.5000*** | -7,580.88 | -7,551.45 |
|             | AUTO      | -0.00016 | 0.0285  | 0.000008** | 0.7000*** | 0.4000*** | —       | 0.5000** | -5,910.60 | -5,881.17 |
|             | INS       | -0.00027 | -0.0147 | 0.00004   | 0.7000*** | 0.4000*** | —       | 0.5000   | -6,304.62 | -6,275.19 |
|             | ALIM      | 0.00042* | 0.0174  | 4.27x10^{-6} | 0.7000*** | 0.4000*** | —       | 0.5000*** | -6,943.00 | -6,913.57 |
|             | TUN20     | 0.00018  | 0.1782*** | 2.83x10^{-6} | 0.7000*** | 0.4000*** | —       | 0.5000*** | -7,854.16 | -7,824.73 |
| EGARCH      | SERF      | -0.00025 | -0.0311 | -2.4557*** | 0.7805*** | 0.2377*** | -0.0761* | —       | -7,527.04 | -7,497.59 |
|             | SAC       | -0.00025 | 0.0564  | 4.3141*** | 0.6036*** | 0.2709*** | -0.1310  | —       | -7,488.36 | -7,458.92 |
|             | IND       | -0.00006 | 0.1267*** | 1.8930*** | 0.8280*** | 0.3277*** | -0.0409* | —       | -6,658.25 | -6,628.82 |
|             | FIN       | -0.00015 | 0.1280*** | -1.5242*** | 0.8857*** | 0.4119*** | 0.1315** | —       | -7,821.03 | -7,791.59 |
|             | DIS       | -0.00027 | 0.0629*  | 4.7983*** | 0.5537*** | 0.2703*** | -0.1401  | —       | -7,420.28 | -7,390.85 |
|             | CONST     | 0.00028  | 0.0514  | -1.9267*** | 0.8398*** | 0.4176*** | 0.0590   | —       | -7,200.43 | -7,171.00 |
|             | BAT       | -0.00023 | 0.1198*** | -1.7127*** | 0.8387*** | 0.3529*** | -0.0381** | —       | -6,040.30 | -6,010.86 |
|             | BASE      | 0.00060*** | 0.0513  | -1.1105*** | 0.9049*** | 0.2521*** | 0.0154   | —       | -6,782.60 | -6,753.17 |
|             | BANK      | 0.00008  | 0.1312*** | -1.6812*** | 0.8714*** | 0.4474*** | 0.1260** | —       | -7,636.97 | -7,607.54 |
|             | AUTO      | -0.00028 | 0.0193  | -1.2020*** | 0.8872*** | 0.2865*** | 0.0604   | —       | -5,908.38 | -5,878.94 |
|             | INS       | -0.00012 | -0.0095 | -6.1208*** | 0.3916*** | 0.3447*** | 0.3233** | —       | -6,790.03 | -6,760.59 |
|             | ALIM      | 0.00043* | 0.0286  | -1.1734*** | 0.9041*** | 0.3073*** | 0.0857   | —       | -6,968.96 | -6,939.53 |
|             | TUN20     | 0.00015  | 0.1947*** | -2.3543*** | 0.8134*** | 0.4541*** | 0.0179   | —       | -7,917.18 | -7,887.74 |
| FIEGARCH     | SERF      | -0.00024* | -0.0296 | -0.5230*  | 0.6035*** | 0.2077*** | -0.0201  | 0.309**  | -7,527.04 | -7,492.71 |
|             | SAC       | -0.00028* | 0.0589*  | -0.2146** | -0.1722  | 0.1953*** | -0.0769** | 0.627**  | -7,494.08 | -7,460.75 |
|             | IND       | -6.49x10^{-6} | 0.1231*** | -0.5165** | 0.5173*** | 0.2986*** | -0.0126  | 0.358**  | -6,656.26 | -6,621.92 |
|             | FIN       | 0.00003  | 0.1356*** | -0.4424*** | 0.3378*** | 0.5211*** | 0.0811** | 0.666**  | -7,832.10 | -7,797.76 |
|             | DIS       | -0.00027* | 0.0656** | -0.1631** | -0.2883  | 0.1636*** | -0.0768** | 0.687**  | -7,425.84 | -7,395.50 |
|                | C     | AR(1) | A     | GARCH(1) | ARCH(1) | LEV(1)/α | Fraction | AIC     | BIC    |
|----------------|-------|-------|-------|----------|---------|----------|----------|---------|--------|
| CONST          | 0.00032** | 0.0489*  | −0.5164*** | 0.4001*** | 0.3921*** | 0.0436*  | 0.422*** | −7,205.59 | −7,173.25 |
| BAT            | −0.00024 | 0.1161*** | −1.416*   | 0.8699*** | 0.3288*** | −0.0130  | 4.57·10^-8 | −6,035.64 | −6,001.30 |
| BASE           | 0.00057*** | 0.0453  | −0.2660*** | 0.2632    | 0.2649*** | 0.0176   | 0.573***  | −6,791.95 | −6,761.61 |
| BANK           | 0.00009 | 0.1312*** | −0.4698*** | −0.1701*  | 0.5377*** | 0.0821*** | 0.623***  | −7,645.64 | −7,611.30 |
| AUTO           | −0.00043 | 0.0060  | −0.4130*** | −0.0601  | 0.4156*** | 0.0601*** | 0.559***  | −5,919.57 | −5,885.23 |
| INS            | −0.00011 | −0.0101 | −0.4817*** | −0.3227** | 0.3460*** | 0.0965*** | 0.499***  | −6,801.96 | −6,767.62 |
| ALIM           | 0.00048** | 0.0254  | −0.3635*** | 0.4369*** | 0.3170*** | 0.0532** | 0.477***  | −6,974.88 | −6,941.54 |
| TUN20          | 0.00022*  | 0.1768*** | −0.5442*** | 0.0854    | 0.4894*** | 0.0241   | 0.506     | −7,922.69 | −7,888.35 |
| TGARCH model   |       |       |       |          |         |         |          |         |        |
| SERF           | −0.00026 | −0.0243 | 4.57·10^-6**** | 0.7656*** | 0.0838*** | 0.0141   | —         | −7,524.96 | −7,495.52 |
| SAC            | −0.00025 | 0.0499  | 4.33·10^-6**** | 0.7920*** | 0.0543**  | 0.0417   | —         | −7,489.77 | −7,460.34 |
| IND            | −4.47·10^-6 | 0.1187*** | 1.01·10^-5**** | 0.7066*** | 0.1510*** | 0.0349   | —         | −6,655.64 | −6,624.20 |
| FIN            | 8.73·10^-5 | 0.1222*** | 2.35·10^-6**** | 0.6810*** | 0.3050*** | −0.0839* | —         | −7,815.57 | −7,786.13 |
| DIS            | −0.00024 | 0.0541  | 4.43·10^-6**** | 0.8008*** | 0.0522**  | 0.0376   | —         | −7,424.08 | −7,394.64 |
| CONST          | 0.00032*  | 0.0475  | 4.77·10^-6**** | 0.6796*** | 0.2511*** | −0.0234  | —         | −7,202.63 | −7,173.20 |
| BAT            | −0.00027 | 0.1113*** | 0.00001*** | 0.7043*** | 0.1683*** | 0.0169   | —         | −6,040.02 | −6,010.58 |
| BASE           | 0.00055** | 0.0513  | 3.93·10^-6**** | 0.8297*** | 0.1176*** | −0.0030  | —         | −6,789.58 | −6,760.14 |
| BANK           | 0.00009 | 0.1146*** | 2.78·10^-6**** | 0.6621*** | 0.3438*** | −0.0926* | —         | −7,632.95 | −7,603.52 |
| AUTO           | −0.00006 | 0.0356  | 0.00001*** | 0.8165*** | 0.1415*** | −0.0294  | —         | −5,907.02 | −5,877.58 |
| INS            | −0.00018 | −0.0375 | 0.00005*** | 0.0347   | 0.3217*** | −0.2035** | —         | −6,796.25 | −6,766.81 |
| ALIM           | 0.00037*  | 0.0194  | 0.000004*** | 0.7593*** | 0.1861*** | −0.0141  | —         | −6,970.46 | −6,941.03 |
| TUN20          | 0.00019 | 0.1826*** | 2.98·10^-6**** | 0.6675*** | 0.2190*** | 0.0119   | —         | −7,911.07 | −7,881.63 |

*Indicate that the estimators are significant at 10% level.
**Indicate that the estimators are significant at 5% level.
***Indicate that the estimators are significant at 1% level.
Bold values represent the minimum values of the information criteria for which the best GARCH model has been chosen.
|                | C     | AR(1)  | A     | GARCH(1) | ARCH(1) | LEV(1)/δ | Fraction | AIC       | BIC       |
|----------------|-------|--------|-------|----------|---------|----------|----------|-----------|-----------|
| **FIGARCH model** |       |        |       |          |         |          |          |           |           |
| SERF           | 0.00005 | 0.2606 | 0.00003 | 0.7000 | 0.4000 | —        | 0.500    | −549.72   | −535.29   |
| SAC            | −0.00076 | 0.1433 | 0.00002 | 0.7000 | 0.4000 | —        | 0.500    | −526.41   | −511.97   |
| IND            | −0.00104 | 0.3735*** | 0.00002 | 0.5227** | 0.8419*** | —        | 2.58·10⁻⁷ | −520.56   | −506.12   |
| FIN            | −0.0017 | 0.3617*** | 1.39·10⁻⁶ | 0.7000** | 0.4000 | —        | 0.500**  | −580.99   | −566.55   |
| DIS            | −0.00074 | 0.0926 | 0.00003 | 0.2302 | 0.2353 | —        | 0.113    | −529.75   | −515.31   |
| CONST          | −9.25·10⁻⁶ | 0.3848*** | 2.46·10⁻⁶ | 0.7000** | 0.4000 | —        | 0.500*   | −518.72   | −504.28   |
| BAT            | −0.00077 | 0.3204*** | 0.00003 | 0.2407 | 0.3108 | —        | 0.146    | −512.58   | −498.14   |
| BASE           | −0.00267*** | 0.2828** | 0.00003 | 0.4064 | 0.8383** | —        | 1.17·10⁻⁷ | −500.44   | −486.01   |
| BANK           | −0.00012 | 0.3089*** | 1.61·10⁻⁶ | 0.7000** | 0.4000 | —        | 0.500**  | −564.06   | −549.62   |
| AUTO           | −0.00194 | −0.0606 | 8.85·10⁻⁶ | 0.7115 | 0.0296 | —        | 1.000    | −472.16   | −457.72   |
| INS            | −0.00070 | 0.1466 | 0.00002 | 0.7000 | 0.4000 | —        | 0.500    | −518.58   | −504.14   |
| ALIM           | 0.00036 | 0.3633*** | 7.09·10⁻⁶ | 0.7000** | 0.4000 | —        | 0.500    | −494.16   | −479.72   |
| TUN20          | 0.00008 | 0.4274*** | 1.44·10⁻⁶ | 0.7000** | 0.4000 | —        | 0.500**  | −570.87   | −556.43   |
| **EGARCH model** |       |        |       |          |         |          |          |           |           |
| SERF           | −0.0001 | 0.2609** | −7.6255 | 0.2319 | −0.3540 | −0.0599 | —        | −599.82   | −585.38   |
| SAC            | 0.000046 | 0.0378 | −1.7399 | 0.8264*** | 0.0531 | −0.9999 | —        | −536.14   | −521.70   |
| IND            | −0.00187* | 0.2980** | −1.3949 | 0.8698*** | 0.2131 | −0.9999 | —        | −525.30   | −510.86   |
| FIN            | −0.00054 | 0.3382** | −0.9538*** | 0.9353*** | 0.3645 | −0.5003 | —        | −592.87   | −578.43   |
| DIS            | −0.00026 | −0.0154 | −2.5188 | 0.7424 | 0.0414 | −0.9999 | —        | −526.62   | −512.18   |
| CONST          | 0.00025 | 0.3437** | −1.8143** | 0.8815*** | 0.2933*** | 0.1369 | —        | −534.18   | −519.74   |
| BAT            | −0.00088 | 0.3184*** | −4.2340 | 0.5765* | 0.4873* | −0.3666 | —        | −514.05   | −499.61   |
| BASE           | −0.00324*** | 0.2194 | −2.9848 | 0.7088** | 0.3724 | −0.7391 | —        | −503.63   | −489.19   |
| BANK           | −0.00040 | 0.2772* | −0.9338*** | 0.9371*** | 0.3767 | −0.4497 | —        | −576.20   | −561.76   |
| AUTO           | −0.00281* | −0.0545 | −0.8773** | 0.9256*** | 0.3181* | −0.5229 | —        | −472.88   | −458.44   |
| INS            | −0.00077 | 0.1790 | −9.1116 | 0.0460 | 0.0727 | 0.9999 | —        | −529.91   | −515.47   |
| ALIM           | 0.00006 | 0.3112*** | −1.6963 | 0.8649*** | 0.2913* | −0.1418 | —        | −506.32   | −491.88   |
| TUN20          | −0.00015 | 0.4375*** | −1.0962** | 0.9302*** | 0.4949** | −0.1510 | —        | −585.43   | −570.98   |
| **FIEGARCH model** |       |        |       |          |         |          |          |           |           |
| SERF           | −0.00059 | 0.2801** | 0.172* | −0.889*** | −0.2204 | −0.2317 | 1.00**   | −603.01   | −586.17   |
| SAC            | −0.00062 | 0.0037 | 0.362*** | −0.906*** | −0.5059*** | −0.4786*** | 0.956*** | −558.22   | −541.37   |
| IND            | −0.01842** | 0.2860*** | −1.049 | 0.8985*** | 0.1269 | −0.2672 | 1.4·10⁻⁸ | −523.82   | −506.98   |
| FIN            | −0.00022*** | 0.2758*** | −1.239*** | −0.8070*** | 1.3313*** | −0.1234** | 0.778*** | −608.23   | −591.38   |
| DIS            | −0.00017 | −0.0082 | 0.400*** | −0.9529*** | −0.5908*** | −0.4228*** | 0.972*** | −551.97   | −535.12   |

(Continues)
## Table 3  (Continued)

|       | C        | AR(1)    | A       | GARCH(1) | ARCH(1) | LEV(1)/δ | Fraction | AIC     | BIC     |
|-------|----------|----------|---------|----------|---------|----------|----------|---------|---------|
| **CONST** | 0.00038  | 0.3282*** | –0.862*** | 0.1614   | 1.0108*** | 0.1315   | 0.731*** | –529.54 | –512.69 |
| **BAT**  | –0.00088 | 0.3277*** | –3.125  | 0.6926   | 0.3414   | –0.1315  | 7.86×10⁻⁸ | –511.79 | –494.94 |
| **BASE** | –0.00332** | 0.2487*  | –1.172  | 0.8754*** | 0.0609   | –0.3474** | 9.12×10⁻⁹ | –501.62 | –484.77 |
| **BANK** | –0.00021 | 0.2608**  | –0.620*** | –0.6503*** | 0.7669*** | –0.1911 | 0.935*** | –573.94 | –557.10 |
| **AUTO** | –0.00278** | –0.0613  | –0.843  | 0.9275*** | 0.2933*  | –0.1838 | 3.38×10⁻⁷ | –471.24 | –454.39 |
| **INS**  | 0.00055  | 0.1482*   | 0.304*  | –0.4700  | –0.4506* | 0.3555** | 0.911*** | –531.17 | –514.32 |
| **ALIM** | 0.00016  | 0.3226*** | –0.5962 | 0.8152*  | 0.5501** | –0.0291 | 0.417    | –504.93 | –488.09 |
| **TUN20** | –0.00016 | 0.4325*** | –0.7258 | 0.9273*** | 0.4278*  | –0.0633 | 0.121    | –584.15 | –567.31 |
| **TGARCH model** |         |          |         |          |         |          |          |         |         |
| **SERF** | –0.0010  | 0.2409**  | 0.00003* | 0.3501   | –0.1575 | –0.0653 | —        | –603.83 | –589.39 |
| **SAC**  | –0.00069 | –0.0144   | 0.0000006* | 0.9037*** | –0.1273*** | 0.2372** | —        | –553.49 | –539.05 |
| **IND**  | –0.00184* | 0.2361**  | 8.49×10⁻⁶** | 0.9291*** | 0.2354 | 0.4012** | —        | –528.05 | –513.61 |
| **FIN**  | –0.00031 | 0.3335*** | 1.45×10⁻⁵** | 0.7942*** | –0.1007 | 0.4660** | —        | –595.68 | –581.24 |
| **DIS**  | –0.00061 | –0.0534   | 0.0000007* | 0.8977*** | –0.1497*** | 0.2699** | —        | –548.90 | –534.46 |
| **CONST** | 0.00030  | 0.3145*   | 1.64×10⁻⁶ | 0.5044** | 1.042**  | –0.5934 | —        | –533.22 | –518.78 |
| **BAT**  | –0.00106 | 0.3271*** | 0.00004  | 0.3948   | 0.0805   | 0.1936   | —        | –513.37 | –498.93 |
| **BASE** | –0.00273*** | 0.2704*** | 0.00002*** | 0.7947*** | 0.1363*** | 0.5180*** | —        | –506.95 | –492.51 |
| **BANK** | –0.00030 | 0.2776**  | 0.000002** | 0.7994*** | 0.12578** | 0.4849*** | —        | –578.29 | –563.85 |
| **AUTO** | –0.00223 | –0.0851   | 8.02×10⁻⁶* | 0.7735*** | 0.0726 | 0.2241 | —        | –473.92 | –459.48 |
| **INS**  | –0.00088 | 0.0912    | 0.00004  | 0.7875   | 0.1693   | –0.3313 | —        | –531.56 | –517.11 |
| **ALIM** | 0.000346 | 0.3624*** | 7.30×10⁻⁶* | 0.6484*** | 0.2957 | 0.0997 | —        | –504.16 | –489.72 |
| **TUN20** | 0.000075 | 0.4283*** | 0.000002 | 0.6883*** | 0.2911 | 0.0356 | —        | –585.48 | –571.04 |

*Indicate that the estimators are significant at 10% level.

**Indicate that the estimators are significant at 5% level.

***Indicate that the estimators are significant at 1% level.

Bold values represent the minimum values of the information criteria for which the best GARCH model has been chosen.
market indices are not dominated by uninformed investors but instead by informed investors. All the sectorial indices return volatilities are characterized by a very high persistence. This strong persistence, as derived from the sum of both the ARCH and GARCH coefficients.

4 | CONCLUSION

This study analyses the volatility dynamics of the Tunisian stock market before and during the COVID-19 outbreak using GARCH family models. The data covers the period between 4 January 2016 and 30 April 2020, and the COVID-19 crisis. By using four GARCH specifications, namely FIGARCH, FIEGARCH, EGARCH and TGARCH models, we show that, during the COVID-19 crisis, the EGARCH is the appropriate model for building constructs materials, construction and food and beverage sector returns volatilities while the FIEGARCH is the best model for service, financials and distribution sector return volatilities. Indeed, the rest of the Tunisian sectorial stock market return volatilities are modulated by a TGARCH model.

In addition, it seems that following the COVID-19 outbreak, volatility is more persistent in all series. The results prove that building constructs materials, construction and food and beverage sector return volatilities have an insignificant asymmetric effect while consumer service, financials and distribution, industrial, basic materials and banks sector return volatilities have relatively high positive and significant asymmetric effect compared with those during the pre-COVID-19 period. Finally, the findings show that financial services, automobile and parts, insurance and TUNINDEX20 sectors have an insignificant leverage effect. This result can be explained by the fact that the positive shocks increase the volatility by high than negative shocks which are in stark contrast to the positive coefficient.

Our results can thus be useful for investors when accounting for future volatility and implementing hedging strategies. Indeed, the empirical results have implications for both institutional and retail investor risk management as well as for economic and financial policies, highlighting the prevalence of tail behaviour and persistent asymmetric nature of the COVID-19 outbreak.

ENDNOTE

1 Note to the banks and to the financial establishments n ⑥: 2020-17 of 1 April 2020.

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