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Fiscal responses to COVID-19 outbreak for healthy economies: Modelling with big data analytics☆

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ABSTRACT

Fiscal responses to the COVID-19 crisis have varied a lot across countries. Using a panel of 127 countries over two separate subperiods between 2020 and 2021, this paper seeks to determine the extent that fiscal responses contributed to the spread and containment of the disease. The study first documents that rich countries, which had the largest total and health-related fiscal responses, achieved the lowest fatality rates, defined as the ratio of COVID-related deaths to cases, despite having the largest recorded numbers of cases and fatalities. The next most successful were less developed economies, whose smaller total fiscal responses included a larger health-related component than emerging market economies. The study used a promising big data analytics technology, the random forest algorithm, to determine which factors explained a country's fatality rate. The findings indicate that a country's fatality ratio over the next period can be almost entirely predicted by its economic development level, fiscal expenditure (both total and health-related), and initial fatality ratio. Finally, the study conducted a counterfactual exercise to show that, had less developed economies implemented the same fiscal responses as the rich (as a share of GDP), then their fatality ratios would have declined by 20.47% over the first period and 2.59% over the second one.

1. Introduction

COVID-19 caused a significant negative shock to most countries' economies. A significant research effort has therefore been devoted to understanding how government actions in response to the pandemic affected economic activity. In contrast, far less effort has been devoted to understanding how government actions affected COVID-19 detection and containment. This paper seeks to fill this void.

The pandemic negatively impacted both the real and the monetary sides of the economy in advanced, emerging markets, and less developed countries. In response, governments worldwide implemented fiscal recovery packages, with the key fiscal responses such as automatic insurance mechanisms, social safety nets, tax reductions, and subsidies. While these measures kept the spread of COVID-19 under control, they also led to the detection of more cases. This raises the question of whether these fiscal measures can be used as useful indicators of the spread of COVID-19. The most commonly used statistics in the literature are either unstandardized or standardized measures of COVID-19 cases and deaths, whereby unstandardized variables are placed on the same scale to allow comparisons (Sözen et al., 2022). Another critical statistic for measuring a country's success in fighting the pandemic is the case-fatality ratio, defined as the ratio of COVID-19-related deaths to confirmed COVID-19 cases (Iyanda et al., 2022; Spychalski et al., 2020).

There has been significant attention in the literature to modeling the spread of COVID-19 in terms of the number of cases, the number of deaths, or the case fatality ratio (Basu, 2020; Korolev, 2021), but much less to modeling the impact of fiscal measures on its spread. This paper attempts to fill this void. Big data analytics (BDA) have been employed to detect important factors affecting the spread of the pandemic (Guo et al., 2020). The present study seeks to apply these techniques to investigating the impact of fiscal measures on the spread of COVID-19.

The study addresses the following three main research questions:

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1 To what extent have fiscal responses contributed to the spread and containment of COVID-19?
2 How do fiscal responses and the spread of COVID-19 vary with level of economic development?
3 What can be learned from the BDA-implemented disease spread model in a cross-country study?

To answer these questions, we designed a (panel) cross-country study that collected and analyzed data on fiscal recovery packages and COVID-19 spread statistics for 127 countries over two periods. Period 1 covered September 11 to December 31, 2020, while Period 2 covered January 1 to March 17, 2021. The COVID-19 spread statistics included total number of cases per million, total number of deaths per million, and case fatality ratios. Data on the fiscal recovery packages, taken from the IMF's website, included both health sector support and total financial support measured as percentages of GDP, as announced in October 2020, January 2021, and April 2021. After collecting and structuring the data, we summarized and compared the fiscal measures and corresponding COVID-19 spread statistics in relation to each country's ranking. The rankings were based on the IMF categories of G20 and Non-G20 advanced economies, emerging market economies, and low-income developing countries. The BDA model was then used to analyze the case fatality ratio in the two periods that fell between the three announcement dates of fiscal measures.

The findings show that a country's development level, fiscal expenditure, and fatality ratio almost entirely predicts its fatality ratio throughout the following period. In addition, the findings indicate that the fatality ratios would have declined if less developed countries had implemented the same fiscal responses as rich countries.

This paper is organized as follows. Section 2 summarizes existing studies in the field. Section 3 describes the data sources and the research methodology. Section 4 presents the main findings of this study. Section 5 provides a discussion and concluding remarks.

2. Literature review

A large body of literature has focused on COVID-19's economic impact These include Acıkgoz and Gunay (2020), Baker et al. (2020), Ceylan et al. (2020), Deb et al. (2020), Goldberg and Reed (2020), Susskind and Vines (2020), and Padhan and Prabheesh (2020).

Only a few studies have considered the fiscal policy perspective. Makin and Layton (2021), for example, criticized fiscal policy responses for several country groups during the pandemic, specifically regarding the role of the tax system, public debt, and budget deficit. They concluded that in addition to spending and subsidy levels, speed, simplicity, and lack of access were vital factors for withstanding COVID-19. Devereux et al. (2020) evaluated discretionary fiscal policy in the UK over three phases of the outbreak: the overall disruption phase, the recovery phase, and the long run. They found that subsidizing the costs of returning workers provided significant and speedier recovery packages. Ando et al. (2021) evaluated Japan's fiscal measures within various supplementary budgets between January and June 2020. They found that subsidy programs and expanded loans played important roles in supporting the economy's supply side. Chudik et al. (2021) applied a threshold-augmented VAR model to discretionary fiscal policies. They concluded that larger fiscal recovery packages are needed and that most important emerging market economies gained from global macroeconomic policies through the spill-over effect.

Another fiscal policy response worth highlighting is the paycheck protection program (PPP). a novel small business support program that formed part of the initial policy response to the COVID-19 pandemic in the USA. The program relied on private banks to rapidly disburse aid to small businesses. PPP extended 669 billion dollars of forgivable loans in an unprecedented effort to support small businesses affected by COVID-19 (Humphries et al., 2020). PPP's success has been evaluated by various studies and working paper series (Autor et al., 2022; Granja et al., 2020; Hubbard and Strain, 2020).

Maher et al. (2020) conducted a survey study to assess the fiscal responsibility of local governments and non-profit organizations in the USA. They found that the main factor determining their responses to the outbreak was the financial statement. Jose et al. (2020) used high-frequency macroeconomic variables to investigate macroeconomic responses to the pandemic in India. They concluded that the liquidity-enhancing power and overdependence on taxes limited India's economic response, which may offer a lesson for other developing countries.

Overall, the few empirical studies of economic recovery policies either take a theoretical approach to consider just one economy or merely apply descriptive analytics. However, fiscal measures have highly heterogeneous impacts to the outbreak. To the best of our knowledge, the present study is one of the first aiming to contribute to the literature by conducting research on multiple countries categorized by their development level across different fiscal recovery dimensions, using big data analytical modelling.

3. Data and research method

The two main data sources for this study were the International Monetary Fund (IMF) and Our World in Data (OWID). The IMF's database of fiscal response monitors lists the key fiscal measures taken by governments in response to COVID-19. The monetary value of both the health sector-related and total measures were extracted from this database as a percentage of each country's GDP. The IMF published its first such report in October 2020, listing the fiscal measures that governments had taken since the COVID-19 pandemic began until September 11, 2020 (International Monetary Fund 2020). The IMF then published cumulative quarterly reports on the updated measures. Thus, the second report, published in January 2021, listed all measures taken since the COVID-19 pandemic began until December 31, 2020 (International Monetary Fund 2021), while the third report, published in April 2021, listed all measures taken until March 17, 2021.

The data on the key fiscal measures focus on two discretionary measures, namely total fiscal measures and health-related expenditure measures. This fiscal support includes resources allocated or planned in response to the COVID-19 pandemic since January 2020, focusing on government discretionary measures as automatic stabilizers based on each country's characteristics. The IMF categorizes three types of fiscal support with different near-term and long-term implications for public finances. These fiscal measures are based on three sub-groups of liquidity support: above-line measures of additional spending and forgone revenue; below-the-line measures (equity injections, loans, asset purchases, or debt assumptions), and contingent liabilities refer guarantees (on loans, deposits, etc.). These responses focus on government discretionary measures that supplement to existing automatic stabilizers. The fiscal measures and health expenditure measures also depend on country characteristics. Fiscal policy responses are based on taxation and spending measures to support economic recovery. These include grants to small business owners, additional funding for public services, tax reductions or delays, and financial support. Health expenditure mainly concerns healthcare equipment, hospital capacity, vaccines, free health services, and COVID testing.

Since this is a cross-country study, standardized data on COVID-19 spread statistics were collected to enable a fair comparative analysis. For each end date of the three IMF reports, total cases (per million) and total deaths (per million) were retrieved from the OWID (2020b) database. Thus, for each country, the study data set included the total number of cases (per million) and deaths (per million) from the date of the first COVID-19 case until September 11, 2020, December 31, 2020, and March 17, 2021. For each of these three end dates, case fatality ratios, the ratio of the total number of deaths to the total number of cases (per million), were also calculated to represent COVID-19 spread. The IMF's country classification system (advanced economies, emerging market economies, and less developed economies) was used as the variable denoting each study country's economic development level.

After collecting all the data, essential pre-processing tasks were conducted to obtain the structured study data set. In this step, countries with missing or inconsistent data on any of the study variables were excluded from further analysis. The resulting data set included panel data on 127 countries for the end dates of the three IMF reports. To characterize the study variables, the main descriptive statistics of the countries were calculated for each development group.

Based on the end dates of the three IMF reports, these two periods were defined. Period 1 covered September 11 to December 31, 2020, while Period 2 covered January 1 to March 17, 2021. Data from Period 1 was used to show whether fiscal measures taken until September 11, 2020, could help to understand and model COVID-19 spread in the next quarter until December 31, 2020. Similarly, data from Period 2 was used to show whether fiscal measures taken until December 31, 2020, could help understand and model COVID-19 spread in the next quarter until March 17, 2021. For both study periods, the relationships between the study variables were shown in a correlation matrix created in heat map form.

This study aimed to model each country's case fatality ratio in each study period. The input variables for Model 1 were country grouping, the case fatality ratio as of September 11, 2020, and the health sector and total fiscal measures implemented by September 11, 2020. Model 1 modelled the case fatality ratio as of December 31, 2020. Likewise, the input variables of Model 2 for modeling case fatality ratio as of March 17, 2021, were country grouping, the case fatality ratio as of December 31, 2020, and the two fiscal measures implemented by December 31, 2020. Additionally, to test the model's forecasting performance, the model obtained with data from Period 1 was used to estimate the case fatality ratios of the study countries for March 17, 2021, that is, three months ahead. One of the most widely used and best-performing big data analytics methods, *Random Forest,* was used to implement the models. Model performances was evaluated based on coefficient of determination (R^2), mean absolute percentage error (MAPE), and root means square error (RMSE) statistics.

The final analysis was a counterfactual exercise of creating "What if?" scenarios with the models for the two time periods to further demonstrate the effects of the fiscal measures. This analysis first counterfactually estimated what the case fatality ratio in less developed countries would have been had they implemented the same financial measures as the advanced countries actually did. The analysis was then repeated for the opposite counterfactual case to estimate what the case fatality ratio in advanced economy countries would have been had they implemented the same fiscal measures as the less developed countries actually did. For the first scenario, the predictions were obtained by replacing the actual fiscal measures statistics of the less developed countries with the highest fiscal measures observed within the advanced economies and re-running the model with these modified values. For the opposite case, the predictions were obtained by replacing the actual fiscal measures statistics of the advanced economies with the lowest fiscal measures observed within the less developed countries and re-running the model with the replaced statistics. The findings were evaluated by visualizing the comparison between the predicted and actual values.

Fig. 1 summarizes the data retrieval and research method.

As Fig. 1 shows, the research method had five sequential stages: data collection, data preparation, data exploration, modeling, and evaluation. Table 1 lists the study variables and their notations for each period.

4. Results

4.1. Data exploration results

The study data set included 127 countries. In terms of their development levels, 29 were advanced economies, 55 were emerging markets, and 43 were less developed. For each study variable, the average values at the three announcement dates were obtained for each country. Fig. 2 presents the main descriptive statistics for these variables as box and whisker plots for each development level group.

As Fig. 2 shows, countries with advanced economies implemented the largest total fiscal measures, followed by emerging market countries and then less developed (Fig. 2a). Regarding health-related fiscal measures, advanced economies again implemented the highest largest fiscal measures, while less developed countries implemented higher health-related financial support than emerging markets (Fig. 2b). The advanced economies had both the most total cases (per million) and total deaths (per million), followed by emerging market countries, and

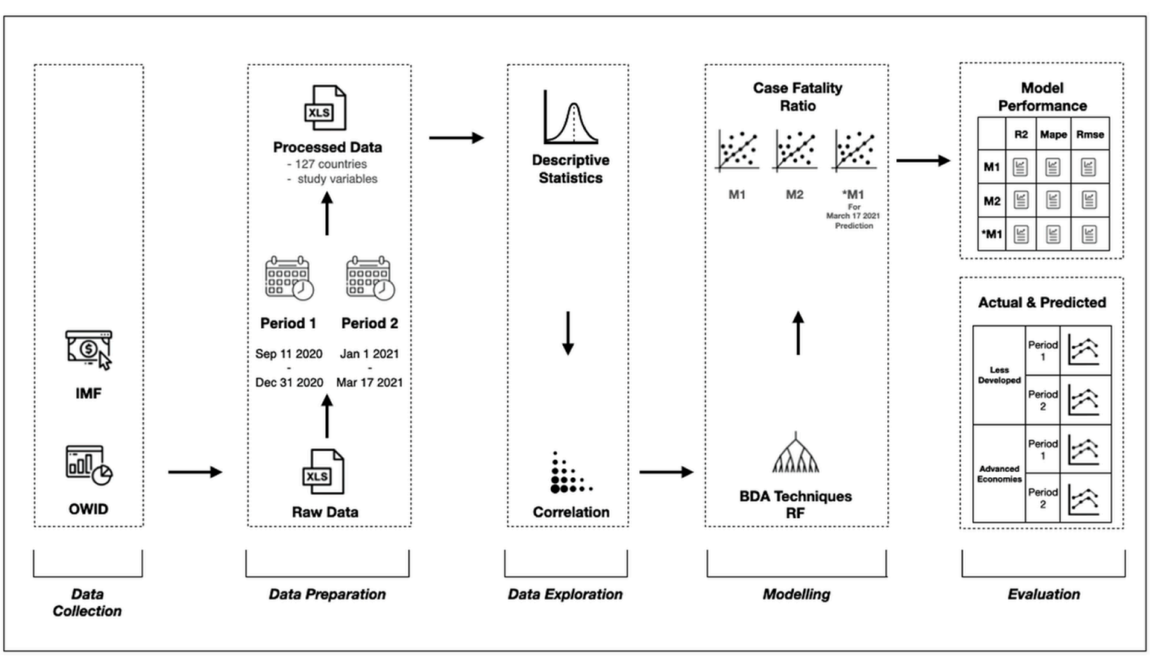

Fig. 1. Research flow chart.

Table 1
Variable definitions and notations.

Notation	Variable label
$FST1_i$	total financial support* of country i until Sep 11, 2020 i=1,…,127
$FSH1_i$	health sector financial support* of country i until Sep 11, 2020 i=1, …,127
$FST2_i$	total financial support* of country i until Dec 31, 2020 i=1,…,127
$FSH2_i$	health sector financial support* of country i until Dec 31, 2020 i=1, …,127
$FST3_i$	total financial support* of country i until Mar 17, 2021 i=1,…,127
$FSH3_i$	health sector financial support* of country i until Mar 17, 2021 i=1, …,127
$TCpm1_i$	total cases (per million) of country i until Sep 11, 2020 i=1,…,127
$TDpm1_i$	total deaths (per million) of country i until Sep 11, 2020 i=1,…,127
$CFR1_i$	case fatality ratio** of country i until Sep 11, 2020 i=1,…,127
$TCpm2_i$	total cases (per million) of country i until Dec 31, 2020 i=1,…,127
$TDpm2_i$	total deaths (per million) of country i until Dec 31, 2020 i=1,…,127
$CFR2_i$	case fatality ratio*** of country i until Dec 31, 2020 i=1,…,127
$TCpm3_i$	total cases (per million) of country i until Mar 17, 2021 i=1,…,127
$TDpm3_i$	total deaths (per million) of country i until Mar 17, 2021 i=1,…,127
$CFR3_i$	case fatality ratio**** of country i until Mar 17, 2021 i=1,…,127
Rank	Country grouping based on development level

* financial support as a percentage of GDP

** $CFR1_i = \frac{TDpm1_i}{TCpm1_i}$

*** $CFR2_i = \frac{TDpm2_i}{TCpm2_i}$

**** $CFR3_i = \frac{TDpm3_i}{TCpm3_i}$

then less developed (Fig. 2c and d). Finally, advanced economies had the smallest case fatality ratios, whereas emerging market countries had the largest. Thus, having smaller total fiscal responses but larger health-related fiscal responses, less developed achieved lower case fatality ratios than emerging market economies (Fig. 2e).

Next, the relationship between the fiscal measures and the total number of COVID-19 cases and deaths for the two periods was analyzed using Pearson correlation coefficients. The results are shown in Fig. 3 in heat map form.

Analysis of the correlation coefficients shown in Fig. 3 between (a) $TCpm1_i$ and$TCpm2_i$, (b) $TCpm2_i$ and $TCpm3_i$, (c) $TDpm1_i$ and $TCpm2_i$, and (d) $TDpm2_i$ and $TDpm3_i$ reveals various relationships. First, past cumulative COVID-19 case and death rates are positively and highly correlated with the corresponding current cumulative statistics. Second, rank is negatively and highly associated with total COVID-19 cases and deaths. In Fig. 3, advanced economies are numbered 1, emerging markets 2, and less developed 3. The correlations indicate that COVID-19 cases and death rates were higher in the most advanced economies. Conversely, most of the less developed countries had lower COVID-19 case and death rates than both the advanced economies and emerging market economies.

Analysis of the correlation coefficients shown in Fig. 3 between (a) $FSH1_i$ and $TCpm2_i$, (b) $FSH2_i$ and $TCpm3_i$, (c) $FSH1_i$ and $TDpm2_i$, and (d) $FSH2_i$ and $TDpm3_i$ reveals that past cumulative health-related fiscal expenditure is positively and moderately related to the next quarter's cumulative COVID-19 case and death rates. The same pattern was observed for total fiscal measures: (a) $FST1_i$ and $TCpm2_i$, (b)$FST2_i$ and $TCpm3_i$, (c) $FST1_i$ and $TDpm2_i$, and (d) $FST2_i$ and $TDpm3_i$ were also positively correlated. These correlations indicate that many countries that increased both total and health-related fiscal measures predict higher case and death rates during the next quarter.

4.2. Modeling results

The analysis indicated that three factors significantly predicted COVID-19 spread during subsequent periods: the country's development level (rank), cumulative values on past periods' fiscal measures, and COVID-19 case and death rates. In light of these findings, the modeling stage of the study was conducted by defining the input variables as country development rank and the total and health-related fiscal measures announced in previous quarters. However, as mentioned earlier, instead of modeling for absolute case and death rates, the case fatality ratio was preferred as the input variable for modeling the next quarter's case fatality ratios since it can better indicate the success of governments in fighting COVID-19 spread. Model performance was tested by implementing the Random Forest algorithm using Scikit-learn programmed in Python. Table 2 summarizes the input and output variables of the proposed models for the two periods and the performance statistics.

Table 2 shows that the coefficients of the determination statistics of the obtained models for the two study periods were high, meaning that the defined input variables successfully explained the variability in the output variables. The MAPE statistics show the average absolute differences between the actual and modeled case fatality ratios for the 127 study countries. Similarly, RMSE shows the square root of the average squared differences between the actual and modeled case fatality ratios for the 127 study countries. As Table 2 shows, Model 2's R^2 value was slightly higher than Model 1's whereas Model 2's MAPE and RMSE values were lower than Model 1's. Thus, the modeled case fatality ratios of the study countries were close to the actual ones for both periods where these differences were smaller in Period 2. To further investigate the models' prediction performances, obtained Model 1 was used to predict the case fatality ratios in March 17, 2021, and these obtained estimated values were then compared with the actual CFR_3^i values. Although the MAPE and RMSE values of these estimations were higher than Model 1's performance, the performance was still acceptable. The MAPE value of 21.41% indicates that the model's three-month forecasting performance was good.

Fig. 4 shows the actual and predicted case fatality ratios for each country.

The actual and predicted $CFR2_i$ values (Fig. 4a) were close to each other for most countries. Similarly, the predicted $CFR3_i$ values (Fig. 4b) were very similar to their actual values. For $CFR3_i$, the difference was larger when Model 1 was used for the three-month prediction (Fig. 4c), although the performance was still noteworthy.

Finally, to highlight the effect of fiscal measures, counterfactual estimations were made using Model 1 and Model 2 by assuming that less developed countries had implemented higher fiscal measures or that advanced economies had implemented lower fiscal measures. To do so, the $FST1_i$ and $FSH1_i$ values of 43 less developed countries were replaced by 19.5 and 1.5, the maximum values for these variables obtained in the advanced economy countries. Model 1 was then rerun with these replacement values to get the predicted $CFR1_i$ values. Similarly, the $FST2_i$ and $FSH2_i$ values of 43 less developed countries were replaced by 19.10 and 5.30 in Model 2 to obtain the predicted $CFR3_i$ values. Fig. 5 shows the actual and predicted values.

Fig. 5 shows that if the less developed countries had implemented higher fiscal measures than the advanced economies, they most would have decreased their case fatality ratios. Of the 43 less-developed countries, 34 (Fig. 5a) had lower $CFR2_i$ predictions than the actual ones while 25 (Fig. 5b) had lower $CFR3_i$ predictions. That is, if the less developed economies had implemented the same fiscal responses as the rich countries, then their fatality ratios would have declined by 20.47% over the first period and 2.59% over the second one. The findings of this counterfactual analysis also show that fiscal measures are significant factors for understanding and modeling the spread and containment of COVID-19.

5. Discussion and conclusion

The cross-country study reported here was designed to model the spread and containment of COVID-19 based on two fiscal measures taken in 127 study countries. Accordingly, the study period was defined in terms of IMF reports listing the fiscal measures taken by these

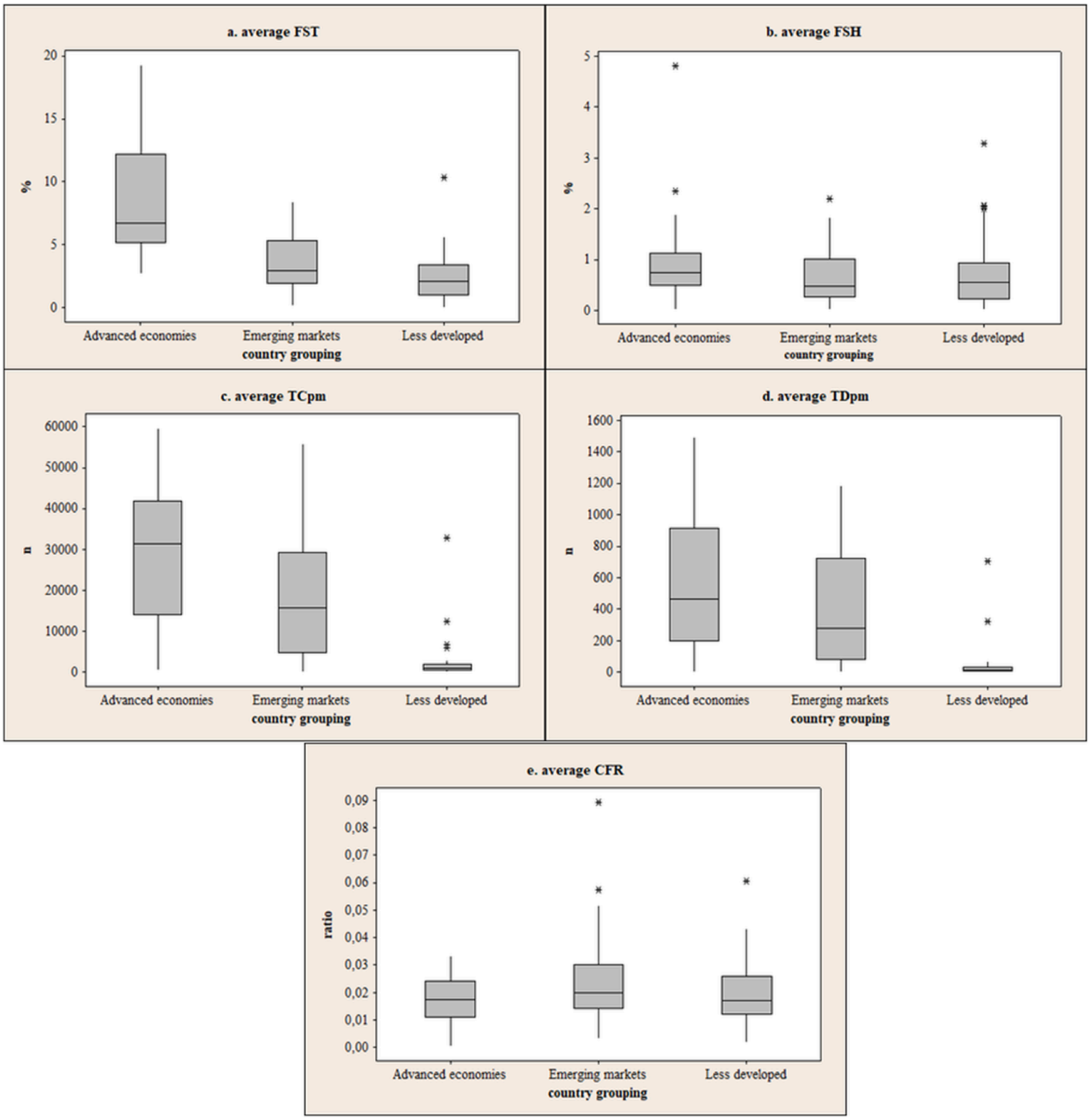

Fig. 2. Box and whisker plots for study variables at each announcement date by development level groups.

countries' governments. The three reports were published in October 2020 (listing measures taken by September 11, 2020), January 2021 (listing measures taken by December 31, 2020), and April 2021 (listing measures taken by March 17, 2021). The cross-country comparative analysis of the retrieved data for the financial measures and COVID-19 case and death rates produced many significant findings, as reported above. These are discussed in more detail in this section.

First, advanced economies implemented the largest total fiscal measures as a percentage of GDP in response to COVID-19 whereas less developed countries implemented the smallest. Second, advanced economies had the highest total COVID-19 case and death rates whereas less developed countries had the lowest. These findings indicate that diagnosing patients is essential for treatment in disease outbreaks. To diagnose and monitor infected people, governments must adopt comprehensive testing policies and contact tracing, which are costly. Thus, countries that can provide such financial support can effectively diagnose cases and their contacts. However, this causes an increase in the number of recorded patients.

Similarly, if more cases are diagnosed, it is highly probable that more deaths due to the outbreak are identified, thereby also increasing recorded death rates. Since advanced economies can provide greater financial support in response to COVID-19, the total case and death rates are higher in these countries. Conversely, since less developed countries cannot implement such financial measures, they had the lowest reported COVID-19 case and death rates. Undoubtedly, however, these low figures do not accurately represent the actual rates due to deficiencies in diagnosis. As Roser et al. (2020) report, in many countries, particularly those with limited testing, actual case rates were much higher than documented cases due to various factors.

In contrast, lower case fatality ratios can provide a good performance indicator in outbreak situations. As shown in this study, emerging market economies had higher case fatality ratios than less developed ones for both periods while advanced economy countries had the lowest values. Thus, based on case fatality ratios, while advanced economies had almost the highest performance, less developed countries performed better than emerging market economies. As discussed earlier, while this could be due to ineffective diagnosis in less developed countries, another important reason could be differences in health-related fiscal measures. Specifically, although the value of total fiscal measures was lower in less developed economies than emerging economies, they spent more on health-related measures.

In this study, a random forest algorithm was used to understand the

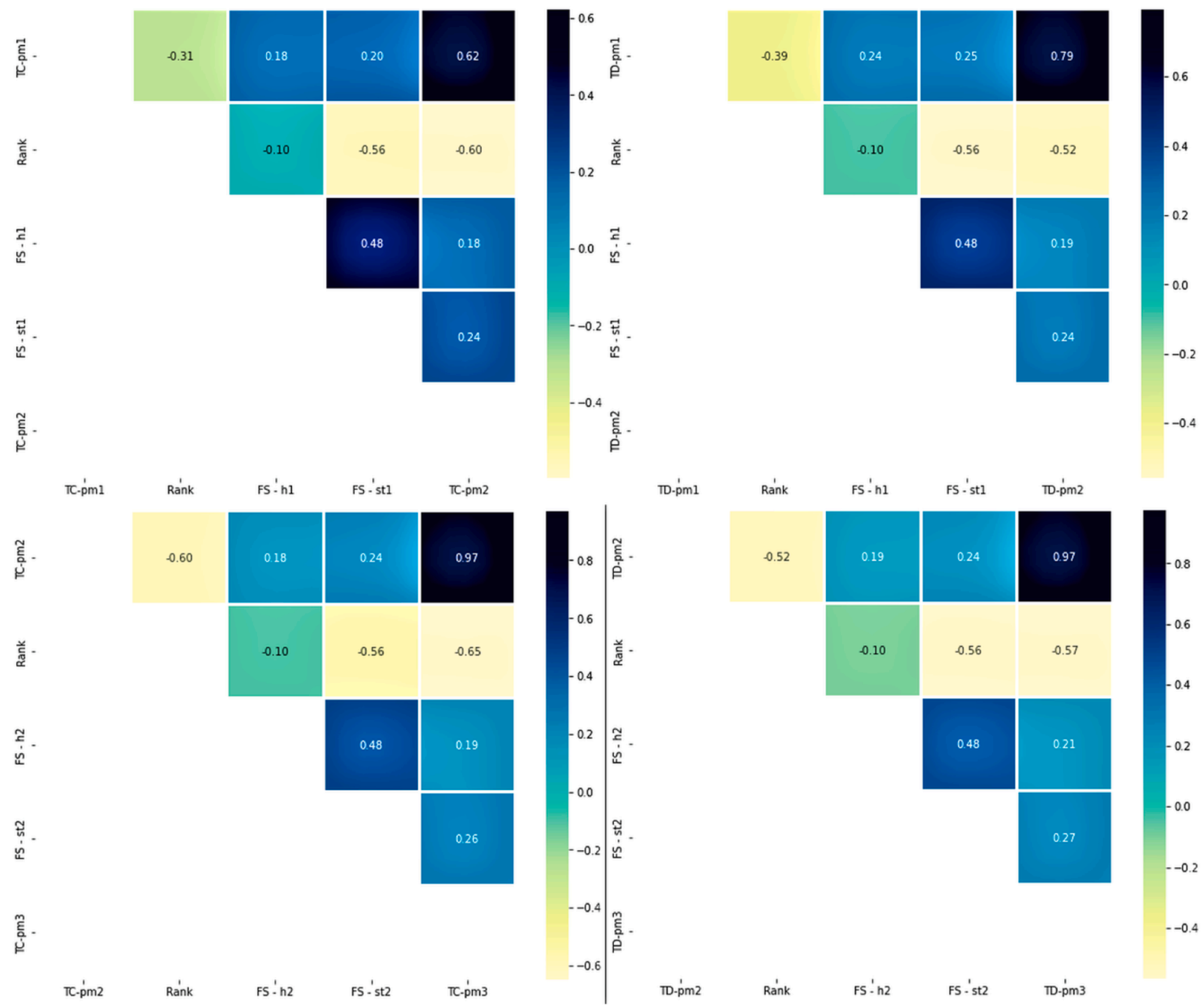

Fig. 3. Heat map of correlation analysis of the study variables.

Table 2
Summary of model performance statistics.

Model	Onput variables	Output variables	R^2	MAPE (%)	RMSE
Model 1	Rank CFR_1^i $FS - st_1^i$ $FS - h_1^i$	CFR_2^i	0.94	12.03	0.002
Model 2	Rank CFR_2^i $FS - st_2^i$ $FS - h_2^i$	CFR_3^i	0.97	7.93	0.002
Model 1 predicts CFR_3^i	Rank CFR_1^i $FS - st_1^i$ $FS - h_1^i$	$CFR_2^i \rightarrow CFR_3^i$	0.94	21.41	0.006

key factors determining a country's case fatality rate. The analysis showed that a country's level of development, fiscal expenditure (both total and health-related), and initial fatality ratio almost entirely predict its fatality ratio over the next period. However, comparison of the performance of the two proposed models for the two study periods indicates that the algorithm performed better in the second period. This is most probably due to unexpected increases in total case and death rates in the first study period. Therefore, the modeling performance was not as high as in Period 2. However, although Model 1, proposed for modeling case fatality ratios in Period 1, performed less than Model 2, both models produced high performance statistics. Model 1 even performed successfully in generating a three-month fatality ratio prediction.

A counterfactual analysis was conducted by estimating the case-fatality ratios for the two study periods as if less developed countries had taken the same level of fiscal measures as advanced economies. Comparison of the predicted and actual ratios indicated that less developed economies would have significantly reduced their case-fatality ratios, thereby highlighting that fiscal responses of sufficient size were critical in fighting COVID-19.

The main limitation of this study is its design. As a cross-country study based on accessing secondary sources for the data set, the main challenge was to retrieve data for all countries and to ensure a fair comparison. This issue was resolved by relying on IMF and OWID data, which are the most reliable data sources in this context. However, this is still a limitation since the statistics announced by governments may not be accurate. In particular, governments may tend to under-report COVID-19-related cases, and far more so for COVID-19-related deaths (Unnikrishnan et al., 2021), which would inflate case-fatality ratios. Future studies using a similar cross-country research design could take such underreporting and mismeasurement issues taken into consideration.

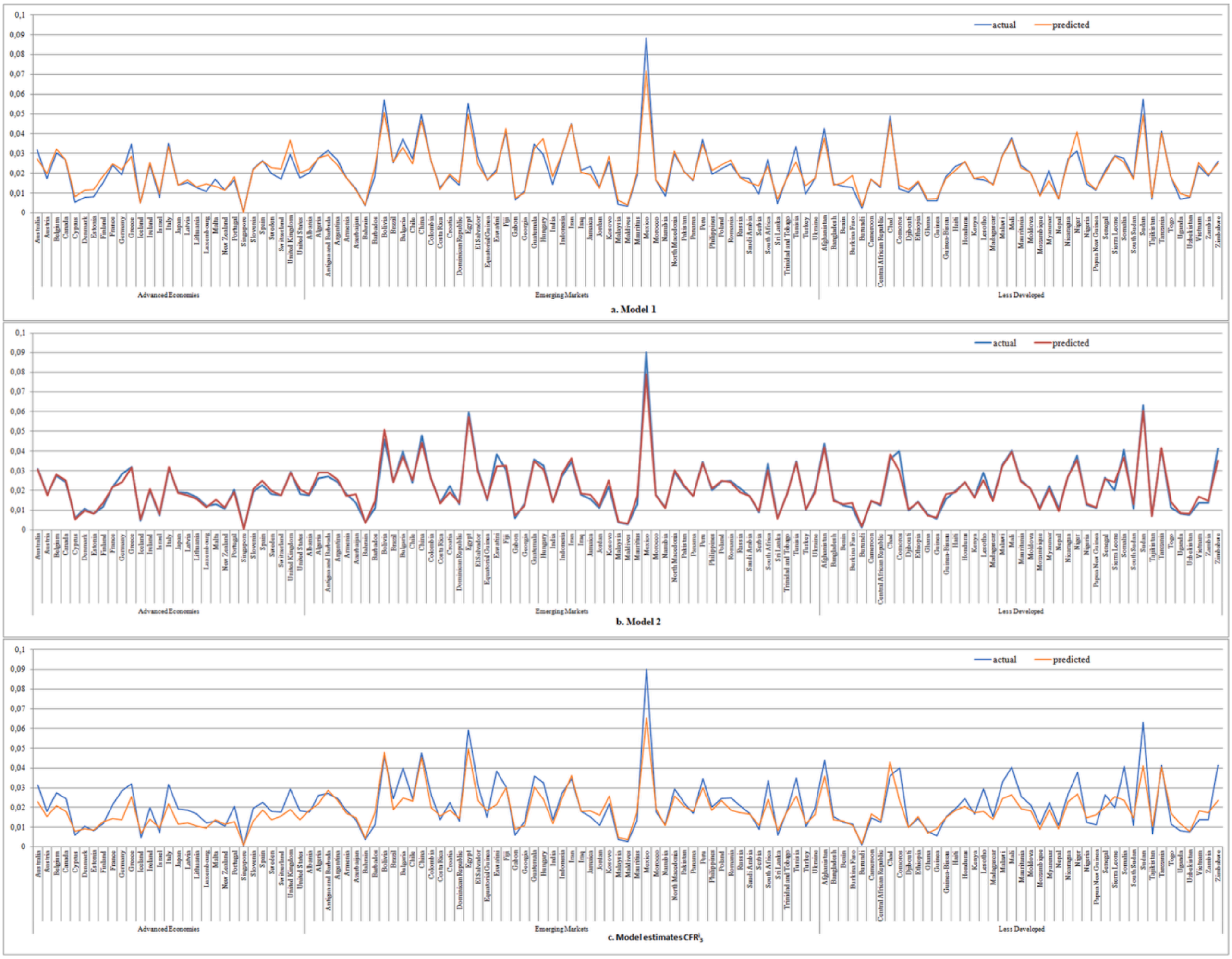

Fig. 4. Actual and predicted case fatality ratios for the study countries grouped by development level.

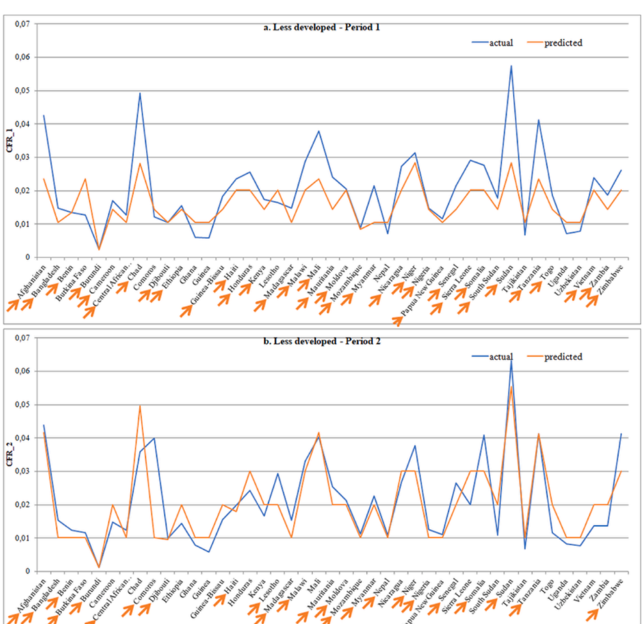

Fig. 5. Actual and predicted $CFR2_i$ and $CFR3_i$values for the "What if?" scenarios.

CRediT authorship contribution statement

Gorkem Sariyer: Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Serpil Kahraman:** Conceptualization, Validation, Data curation, Writing – original draft, Supervision. **Mert Erkan Sözen:** Methodology, Software, Formal analysis, Visualization. **Mustafa Gokalp Ataman:** Conceptualization, Data curation, Supervision.

Data Availability

Data will be made available on request.

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