



ARTÍCULO ORIGINAL

Effect of the COVID-19 pandemic on the number of deaths in Peru: 2017.03–2020.07

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Abstract

The objective of the research is to estimate the excess deaths during the COVID-19 epidemic in Peru. The methodology used for the ARMA models with structural with a structural change in mean. In the first place, the results show that the behavior of the number of deaths before the pandemic follows a first-order autoregressive process (AR (1)) with a change in the mean in the month of March 2020; while by including the period of the pandemic, the behavior of the number of deaths follows the ARMA (1,1) process with two changes in the mean (March 2018 and March 2020). Second, the results show that the excess mortality during the COVID-19 pandemic between March and July 2020 is 58 885 deaths compared to years under normal conditions.

Keywords: ARMA, structural break, COVID-19, deaths, Peru

1. Introduction

Corona virus disease 2019 (COVID-19), which is caused by SARS-CoV-2, SARS-CoV-2 is a highly pathogenic coronavirus that has caused an ongoing worldwide pandemic. Has resulted in significant morbidity and mortality (Khateb, Bosak, & Muqary, 2020). The first positive case of the COVID-19 pandemic in Peru was confirmed on March 6, 2020; while the first death from COVID-19 was reported on thursday, march 19, 2020. He was a 78 year old man, who was consigned in the death certificate: multi organ failure and acute respiratory failure due to pneumonia due to the new coronavirus (Cáceres, Becerra, Mendivil, & Ravelo, 2020). The COVID-19 pandemic spread rapidly in the capital Lima and other regions of the interior of the country where there is a higher population density, which are located mainly in the natural region of the coast and jungle. Currently, the pandemic has spread throughout the country.

Although Peru implemented strict social distancing measures during the first phase of the epidemic, however, is now experiencing one of the largest COVID-19 epidemics in Latin America and in the world (Munayco, Chowell, Tariq, Undurraga, & Mizumoto, 2020).

In epidemiological and public health terms, the effect of the COVID-19 pandemic can be measured from the excess of mortality (Roser, Ritchie, Ortiz-ospina, & Hasell, 2020). Excess mortality refers to the number of deaths above and beyond what is expected under normal conditions.

It is used to measure the impact on mortality of a crisis when not all causes of death are known (Roser et al., 2020). “Excess deaths provide an estimate of the full COVID-19 burden and indicate that official tallies likely undercount deaths due to the virus” (Weinberger et al., 2020). The importance of

estimating excess deaths lies in providing information on the number of deaths associated directly or indirectly with the COVID-19 pandemic (Figueroa et al., 2020). The medical, social and economic impact of the COVID-19 pandemic has unknown effects on the general morality of the population (Banerjee et al., 2020). The COVID-19 pandemic can cause excess mortality during the year 2020 either directly through infection, or indirectly, because patients do not seek the attention of health services for fear of being infected by COVID-19, the inability of the health system to provide effective services to patients other than the COVID-19 disease (Vieira, Peixoto, Aguiar, & Abrantes, 2020).

Likewise, Mannucci, Nreu, & Monami (2020) estimate that the excess number of deaths in Italy during February–March 2020 was much higher than the deaths officially from the COVID-19 pandemic. The impact of the COVID-19 pandemic on the number of excess deaths nationwide (26,701) was considerably higher than the official counts of COVID victims (13,710). That is, there was a difference of 12,991.

The objective of the study is to estimate and predict the behavior of the number of deaths in Peru during and before the COVID-19 pandemic, in order to estimate excess mortality.

2. Methodology

Autoregressive moving average (ARMA) process models are useful for modeling and forecasting time series real data such as the number of deaths from the COVID-19 pandemic. ARMA models are a linear combination of past values of time series, called autoregressive (AR) and a set of uncorrelated errors, called moving average (MA) (Maleki, Mahmoudi, Heydari, & Pho, 2020; Sahai, Rath, Sood, & Singh, 2020). The methodology for estimating the number of deaths, first determines the stationarity of the series under structural breaks. Second, once the stationarity of the series is determined, autoregressive moving averages model (ARMA) are used. The importance of evaluating the presence of structural changes in the mean in time series is of crucial importance. In view of the traditional unit root tests for the evaluation of the seasonality of a time series they fail. A series that is stationary under structural breaks could turn out to be non-stationary if the presence of structural breaks is not taken into account (Perron, 2017). The use of ARMA models under the Box & Jenkins (1976) methodology under structural changes is relevant from the forecasting perspective (Chen & Tiao, 1990; Clements & Hendry, 2006). In this tradition, ARMA models are considered to be composed of a regular component and possibly a component that represents exogenous changes. The latter can be an atypical component or permanent changes at the process level (Clements & Hendry, 2006).

2.1 Unit root test under structural breaks

In order to determine structural changes in the mean in the number of deaths (y), the contrast with two structural breaks by Clemente, Montañés, & Reyes (1998) is used, which is an extension of the contrast with a structural change in mean of Perron and Vogelsang (1992).

Null hypothesis:

$$H_0 : \gamma_t = \gamma_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + u_t \quad (1)$$

As against the alternative hypothesis:

$$H_A : \gamma_t = \mu + d_1 DU_{1t} + d_2 DTB_{2t} + e_t \quad (2)$$

Where TB_1 and TB_2 are the time periods when the mean is being modified. DTB_{it} is pulse variable that takes the value 1 if $t = TB_i + 1$ ($i = 1, 2$) and 0 otherwise, $DU_{it} = 1$ if $t > TB_i$ ($i = 1, 2$) and 0 otherwise. If we consider the case in which the two breaks belong to the innovation outlier, we can test the unit root hypothesis by estimating the following model (Clemente, Montañés, & Reyes, 1998):

$$\gamma_t = \mu + \rho\gamma_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + d_1 DU_{1t} + d_2 DU_{2t} + \sum_{i=1}^k c_i \Delta\gamma_{t-i} + e_t \quad (3)$$

To test the unit root hypothesis, a two-step approach was used. In the 1st step, equation (4) is estimated:

$$y_t = \mu + d_1 DU_{1t} + d_2 DU_{2t} + \hat{y}_t \quad (4)$$

Then, in the second step, carry out the test by searching for the minimum t-ratio was searched and hypothesis $\rho = 1$ was tested with equation:

$$\hat{y}_t = \sum_{i=0}^k w_{1i} DTB_{1t-i} + \sum_{i=0}^k w_{2i} DTB_{2t-i} + \rho \hat{y}_{t-1} + \sum_{i=1}^k c_i \Delta y_{t-i} + e_t \quad (5)$$

2.2 Specification of the AR(1) model for the number of deaths

Before the COVID-19 pandemic (2017m1-2020m3), it is assumed that before the pandemic the number of deaths follows an autoregressive process AR(1) with a change in the mean

$$y_t = \alpha + \beta DU_t(TB_1) + \phi y_{t-1} + e_t \quad (6)$$

where y_t is number of deaths, $DU_1 = 1$ if $t > TB_1$ and 0 otherwise, TB_1 is the time periods when the mean is being modified, e_t is the error term.

2.3 Specification of the AR(1) model for the number of deaths

For the period between January 2017 and July 2020 that includes the situation without pandemic and the situation with pandemic, it is assumed that the behavior of the number of deaths follows an autoregressive process ARMA (1,1) with two changes in the mean

$$y_t = \alpha + \beta_1 DU_{1t}(TB_1) + \beta_2 DU_{2t}(TB_2) + \phi y_{t-1} + \theta_1 \epsilon_{t-1} + \epsilon_t \quad (7)$$

Where $DU_{it} = 1$ if $t > TB_i (i = 1, 2)$ and 0 otherwise, TB_1 and TB_2 are the time periods when the mean is being modified ϵ_{t-1} is the innovation term lagged.

Source of information. The analysis of the number deaths (y) in Peru is carried out with official information from the National Death Information System (SINADEF). The total number of deaths from COVID-19 in Peru provided by the Ministry of Health (MINSa). The analysis is done with monthly information from January 2017 to July 2020.

3. Results

3.1 Unit root test with double mean shifts

The estimation of models (3) and (4) is reported in Table 1. As we can see, the number of deaths, can be considered as stationary around a mean which changes at the beginning of 2018's (2018m3) and at the beginning 2020's (2020m3). The number of deaths in the period 2017m1-2020m7 is a stationary series, since the $t_{\hat{\rho}-1}$ statistic is higher than the $\min t_{\hat{\rho}-1}$ critical value ($t_{\hat{\rho}-1} > \min t_{\hat{\rho}-1}$) at a significance level of 5%. Where $t_{\hat{\rho}-1}$ is the statistic for the unit-root hypothesis $\rho = 1$, TB_1 and TB_2 are the breakpoints.

Table 1. Clemente-Montañés-Reyes unit-root test with double mean shifts, IO model

Parameters	t-statistic
$\hat{d}_1 = 1276$	$t_{\hat{d}_1} = 6.45$
$\hat{d}_2 = 14576$	$t_{\hat{d}_2} = 29.54$
$\hat{\rho}^{-1} = -1.05$	$t_{\hat{\rho}^{-1}} = -9.189$
$\hat{\mu} = 8829$	
$TB_1 = 2018m3$	
$TB_2 = 2020m7$	
5% critical value (min $t_{\hat{\rho}^{-1}} = -5.49$)	
Wald- $\chi^2(4) = 815.27$ prob $> \chi^2(4) = 0.00$	
Sample: 2017m3-2020m07	

In order to predict the expected number of deaths under normal conditions without the COVID-19 pandemic in Peru, an AR (1) model was estimated with a change in the mean in the month of March 2018 in the number of deaths. The result of the estimation shows highly significant statistics at the global (Wald- $\chi^2(2)$) and individual level of the parameters (t_s). Also, the parameter of the autoregressive model AR satisfy stability condition, since the eigenvalues lie inside the unit circle (Table 2).

Table 2. AR(1): 2017m1-2020m2

$y_t = \alpha + \beta DU_t(TB_1) + \phi y_{t-1} + e_t$	
Parameters	t-statistic
$\hat{\alpha} = 8263$	$t_{\hat{\alpha}} = 40.45$
$\hat{\beta} = 1303.93$	$t_{\hat{\beta}} = 5.54$
$\hat{\phi} = 0.475$	$t_{\hat{\phi}} = 3.23$
$TB_1 = 2018m3$	
Wald- $\chi^2(2) = 42.22$	
prob $> \chi^2(2) = 0.0000$	
Eigenvalue stability condition	
Eigenvalue = 0.464 (the eigenvalues lie inside the unit circle)	
AR parameters satisfy stability condition	

Table 3 shows the estimate of the number of deaths for the period 2017m3 and 2020m7. The ARMA (1,1) model estimated with two changes in the mean (2018m3 and 2020m7) is significant at the global and individual level. Likewise, it complies with the stability and invertibility condition required by stationary ARMA models.

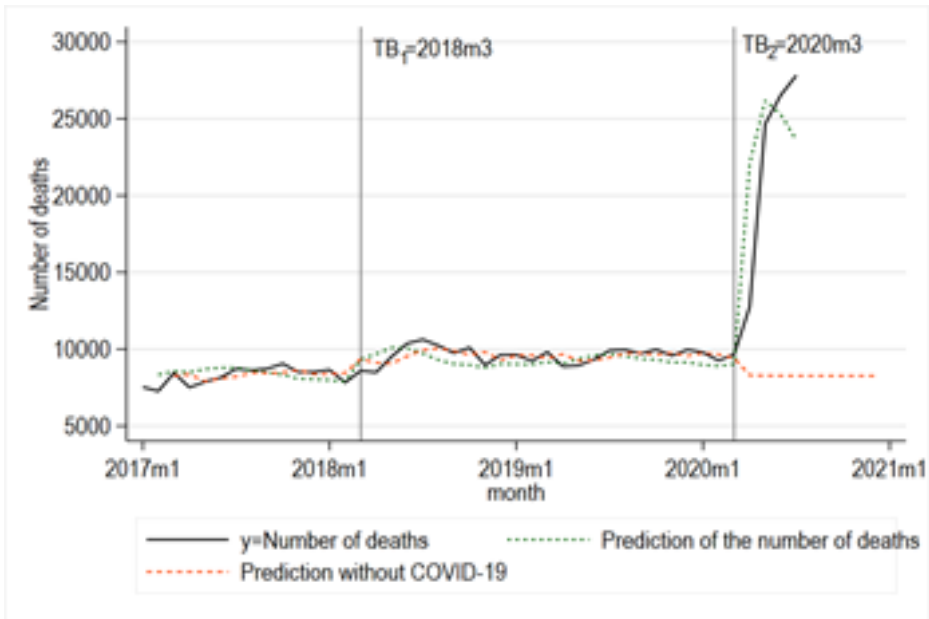
Table 3. ARMA(1,1): 2017m1-2020m7

$y_t = \alpha + \beta_1 DU_{1t}(TB_1) + \beta_2 DU_{2t}(TB_2) + \phi y_{t-1} + \theta_1 e_{t-1} + e_t$	
Parameters	t-statistic
$\hat{\alpha} = 8334$	$t_{\hat{\alpha}} = 19.09$
$\hat{\beta}_1 = 1215$	$t_{\hat{\beta}_1} = 1.9$
$\hat{\beta}_2 = 14305$	$t_{\hat{\beta}_2} = 15.85$
$\hat{\phi} = 0.56$	$t_{\hat{\phi}} = 2.59$
$\hat{\theta} = -0.99$	$t_{\hat{\theta}} = -1.46$
$TB_1 = 2018m3$	
$TB_2 = 2020m7$	
Wald- $\chi^2(4) = 815.27$ prob $> \chi^2(4) = 0.00$	
Eigenvalue stability condition	
Eigenvalue = 0.563 (the eigenvalues lie inside the unit circle)	
AR parameters satisfy stability condition	
Eigenvalue = 0.99	
MA parameters satisfy invertibility condition	

Figure 1 shows the prediction of the number of deaths using the estimated AR (1) model shown in

Table 2, as well as the prediction of the ARMA (1,1) model shown in Table 3. Table 4 shows the total number of deaths during the pandemic for the period between March and July of the year 2020.

Figure 1. Prediction of the number of deaths



During this period the number of deaths reached 101132 which represents 2.38 times (101432/42547) than expected. In other words, there is an excess of deaths compared to what is expected in normal periods of 58 885, of which 19 217 were directly attributed to the COVID-19 pandemic, while approximately 39 668 deaths have yet to be identified if it has a direct or indirect relationship with the COVID-19 pandemic. Until June 20, 2020, Quevedo-Ramírez et al. (2020) estimates for Peru an excess of mortality of 36 322 compared to 9 860 officially deaths from COVID-19, according to the authors, these differences could be explained by the information provided as official and unofficial; the increase in deaths not directly related to COVID-19 as a result of not seeking medical attention; and deaths related to the closure and collapse of hospitals.

Likewise, for the period between March and May 2020, Grillo-Rojas and Romero-Onofre (2020) estimated an excess of 10,406 deaths. The excess of deaths could be related to problems in the health system and the lack of care for other morbidities during the pandemic (Grillo-Rojas & Romero-Onofre, 2020).

Vieira et al., (2020), found that 51% of the excess mortality registered in Portugal was due to other natural causes not classified as COVID-19. The authors argue that some causes would be found that some patients may have died at home or a nursing facility without having had a COVID-19 test, other seriously ill patients may not have sought hospital care for fear of being infected. For example, in the month of March 2020, in Portugal there would be a 48% decrease in the demand for health services and a reduction of 144,000 emergency episodes. Finally, the study by Sempé et al. (2021) attributes among the causes of excess mortality in developing countries can be attributed to a weak health system, the low socioeconomic level of the population and the precariousness of employment.

Table 4. Effect of the COVID-19 pandemic on mortality

Month	Forecast deaths without COVID-19 (1)	Official deaths from COVID-19 (2)	Forecast deaths without COVID-19 plus official deaths from COVID-19 (3)=(1)+(2)	Total number of death according to SINADEF (4)	Unexplained number of deaths (5)=(4)-(3)
2020m3	9423	30	9453	9653	200
2020m4	8303	1021	9324	12747	3423
2020m5	8282	3455	1,737	24665	12928
2020m6	8272	5171	13443	26540	13097
2020m7	8267	9540	17807	27827	10020
Total	42547	19217	61764	101432	39668

4. Conclusion

During the period March and July 2020, the number of official deaths from COVID-19 reached 19,217. The number of deaths without COVID-19 plus the official figures for deaths from COVID was estimated to reach 61,764. However, the number of total deaths according to SENADEF reached the figure of 101,432. That is, there is an excess of 39,668 unexplained deaths in this period.

The number of deaths in Peru is a stationary series with structural changes in the mean. Before the COVID-19 pandemic, the behavior of the number of deaths in Peru follows an autoregressive process AR (1) with a structural change in the mean in the month of March 2018. During the period between January 2017 and July of 2020, which covers the time periods before and after the pandemic, the behavior of the total number of deaths follows autoregressive process ARMA(1,1). Likewise, it was found that the number of deaths in the period between March 2017 and July 2020 is 2.38 times what was projected under normal conditions.

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