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Global lockdown: An effective safeguard in responding to the threat of COVID-19

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Abstract

Rationale, aims, and objectives: The recent outbreak of coronavirus (COVID-19) has infected around 1 560 000 individuals till 10 April 2020, which has resulted in 95 000 deaths globally. While no vaccine or anti-viral drugs for COVID-19 are available, lockdown acts as a protective public health measures to reduce human interaction and lower transmission. The study aims to explore the impact of delayed planning or lack of planning for the lockdown and inadequate implementation of the lockdown, on the transmission rate of COVID-19.

Method: Epidemiological data on the incidence and mortality of COVID-19 cases as reported by public health authorities were accessed from six countries based on total number of infected cases, namely, United States and Italy (more than 100 000 cases); United Kingdom, and France (50 000-100 000 cases), and India and Russia (6000-10 000 cases). The Bayesian inferential technique was used to observe the changes (three points) in pattern of number of cases on different duration of exposure (in days) in these selected countries 1 month after World Health Organization (WHO) declaration about COVID-19 as a global pandemic.

Results: On comparing the pattern of transmission rates observed in these six countries at posterior estimated change points, it is found that partial implementation of lockdown (in the United States), delayed planning in lockdown (Russia, United Kingdom, and France), and inadequate implementation of the lockdown (in India and Italy) were responsible to the spread of infections.

Conclusions: In order to control the spreading of COVID-19, like other national and international laws, lockdown must be implemented and enforced. It is suggested that on-time or adequate implementation of lockdown is a step towards social distancing and to control the spread of this pandemic.

KEYWORDS

credible interval, marginal distribution, posterior distribution, social distancing

1 | INTRODUCTION

The 2019 Coronavirus (COVID-19) outbreak is caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which affects the respiratory system.[1,2] The disease was first identified in Hubei Province, People Republic of China, in late 2019 and has spread globally. The World Health Organization (WHO) declared[3] it as a global pandemic on 11 March 2020; however, by then COVID-19 had already spread to over 100 countries and infected more than 100 000 people, taking over 4000 lives. By 10 April 2020, this outbreak has affected more than 1 560 000 people across the globe (https://ourworldindata.org/coronavirus-source-data). The virus is primarily spread from person-to-person via close contact, either through small droplets released during sneezing, coughing, or talking.[4]

The world had already experienced a COVID-19 like pandemic situation a century ago (ie, 1918-1919), regarding H1N1 influenza (commonly known as Spanish flu).[5] During the H1N1 pandemic, some countries, particularly the United States, tried a range of non-pharmaceutical interventions (NPIs)—measures intended to shrink the spread by avoiding person-to-person contact in the general population.[6]

For any epidemic or pandemic various national[7] and international laws[8-10] are available for slowing down the spread of any infectious disease. Laws should have been prioritized as per the requirement of the situation and supplement the other measures that to be taken in a public healthemergency[10,11]to control the spread of the infection; whereas, law-enforcement takes the action or activity compliance with the objective stated in law, and it includes over governmental bodies like police officials, government officials or officers, etc. Governmental bodies have also tried to reduce the transmission of infectious diseases through the legislative system (International Health Regulations 1981,[12] 2005[13]; National Health Act, 2003[13]).[14,15,16] Law can also contribute to the prevention of infectious diseases by improving access to vaccinations,[17,18] facilitating screening,[12,19] counselling, and education of those at risk of infection. Additionally, law has a responsive role, such as supporting access to treatment, empowering public health authorities to reduce contact with infectious individuals, and to exercise emergency powers in response to disease outbreaks. Essential treatment orders should restrict individual liberty only to the extent necessary to most effectively reduce the risks to public health.[12] The consequences of infectious disease can also induce negative economic effects, leading to economic instability and poor socio-economic growth.[20,21] Governments in each country have come forward to support those who have suffered economic loss due to any infectious disease outbreak.[22-24]

Globally, the core rationale for opting for lockdown was to protect human life from the COVID-19 infection by stopping the transmission of disease across the communities. The other purpose of lockdown was to provide health care services to those infected with COVID-19 virus as well as continuing to facilitate all other general health care facilities.

Governments in most of the countries have adopted lockdown and tried in all possible ways to reduce the human interaction for controlling the spread of COVID-19. However, transmission rate of COVID-19 was found to be increasing even after the implementation of lockdown. In this context, the objectives of the present study are to explore the impact of delayed planning or lack of planning for the lockdown of the country and inadequate implementation of the lockdown, on the transmission rate.

2 | METHODOLOGY

In order to assess the impact of lockdown against the spread of COVID-19; a multiple change point model using the Bayesian regression technique (discussed in Appendix) was adopted for describing the intermittent behaviour in number of registered cases due to the infection by following the stochastic procedure. Here, a change point denotes an instance of the duration of exposure to infection, where the statistical properties before and after that time differ. The change was observed in the rates of transmission, with the duration of exposure (in days). Multiple change points technique derived through Bayesian inferential procedure will provide the maximum litheness in terms of daily registered COVID-19 cases by defining the changes observed in pattern of number of cases on different duration of exposure (in days). The model (Bayesian regression based multiple change point model[25,26]) considered for the present analysis is based on the basic assumptions that (a) number of daily registered cases due to the infection is a linear function of duration of exposure to the infection; (b) number of daily registered cases across the countries is independent. The methodological aspect of Bayesian estimation[27] of change occurred in the pattern of number of daily registered cases in a country due to COVID-19 and its related 95% credible interval were obtained through the posterior distribution. The simulation was performed using R software version 3.6.2.

2.1 | The data

In order to study three shifts or changes in pattern of daily COVID-19 cases, the epidemiological data on the incidence and mortality of COVID-19 cases as reported by public health authorities worldwide was accessed till 11 April 2020 from the website of Our World in Data (https://ourworldindata.org/coronavirus-source-data). For the present study, we considered date-wise number of infected cases due to COVID-19 of six selected countries: Russia, United Kingdom, India, France, Italy, and United States, where country-wide lockdown was scheduled either fully, partially, or not implemented. From an extensive reporting of COVID-19 data across the globe, about 50% of cases were registered from these selected countries. The criteria for selection of these countries were based on total number of infected cases, which was classified in three categories namely more than 100 000 cases (United States and Italy), 50 000 to 100 000 cases (United Kingdom and France), and 6000 to 10 000 cases (India and Russia). Here, the first date of reporting COVID-19 cases, corresponding to each selected country, was considered as the starting day. We have also

TABLE 1 Posterior summaries of mean duration of exposure and the highest density intervals for each change point and other parameters corresponding to each selected country

Parameters		Posterior Mean (95% Credible Interval)					
		Russia	United Kingdom	India	France	Italy	United States
Change points	Cp 1	50 (48-52)	49 (47-54)	54 (49-63)	48 (13-60)	42 (40-44)	60 (59-62)
	Cp 2	55 (54-56)	56 (55-57)	63 (62-68)	59 (48-70)	49 (48-50)	66 (65-67)
	Cp 3	61 (60-62)	62 (61-63)	68 (64-69)	64 (59-70)	60 (59-61)	72 (71-73)
β_1		−17.2 (−56.06-21.1)	−81 (−286-118)	−11.29 (−45.07-22)	−160 (−628-338)	−350 (−627-54)	−345 (−1181.8-517)
β_2		230.9 (159.08-296.4)	992.1 (648.1-1382)	154.65 (66.55-531)	1757.7 (−169-4388)	3176 (2825-3504)	8065 (6276.7-10 122)
β_3		595.8 (531.49-651.1)	2601 (2329.1-2887)	492.1 (297.85-771)	3349 (829-8277)	5618 (5342-5906)	18 641 (17 014.6-20 569)
β_4		1186.4 (119.85-1256.2)	4437.2 (4227.2-4652)	646.41 (559.55-714)	3918.2 (3491-4393)	4186 (3910-4456)	30 248 (29 176.7-31 364)
σ		64.5 (52.55-77.1)	325.5 (271.4-387)	50.06 (41.13-60)	649.6 (503-787)	455 (375-538)	1600 (1347.9-1875)

obtained the full lockdown-related information about India, United Kingdom, France, and Italy from the online published news.

3 | RESULTS

Table 1 summarizes posterior mean estimates of Equation (A1) including each change points (s_j), regression coefficients ($\boldsymbol{\beta}$), SD (σ), and their credible intervals (CrI) for each of the selected countries. Based on the pattern of daily registered cases of COVID-19, the shortest posterior estimate duration of exposure (95% CrI) for first change point(Cp 1) in the daily infected cases, was observed in Italy on 42nd day (40-44 days) of exposure followed by France on 48th day (13-60 days), United Kingdom on 49th day (47-54 days), Russia on 50th day (48-52 days), and India on 54th days (49-63 days). The posterior estimate duration of exposure at first changing point was highest (60th day with 95% CrI [59-62 days]) for the United States compared to other countries in the pattern of daily infected cases.

As far as posterior estimate of second change point(Cp 2) is concerned, the pattern of daily infected cases shifted with respect to first change point within 5 days in Russia, 6 days in the United States, 7 days in United Kingdom and Italy, and highest was 9 days in India and France. If we compare the posterior estimate of third change point (Cp 3) with respect to second change point, shift in the pattern of daily infected cases were observed within 4 days in France, 5 days in India, 6 days in Russia, United Kingdom and United States, and 11 days in Italy.

The six selected countries (Russia, United Kingdom, India, France, Italy, and United States) reported 50% of world's COVID-19 infection cases till 10 April 2020. The posterior estimates of the parameters (in Table 1), $\boldsymbol{\beta}$,σ, s_j, of Bayesian regression-based multiple change point model. Non-informative choice of priors for $\boldsymbol{\beta}$ and σ provided an apparently good fit to the number daily registered cases. The 95% credible interval of their posterior estimates of $\boldsymbol{\beta}$ and σ shows a narrow interval. As our parameters of interest are the point in duration of exposure, where there were shifts in pattern of number of daily registered cases, the 95% credible interval of their posterior estimates for each of the change points were showing a narrow interval and consistent pattern with posterior density as depicted in Figure S1.

In order to understand the impact of delaying lockdown and whether its implementation was effective on the number of daily registered cases of COVID-19 in each of the selected country, two-way comparisons are presented in Table 2. Firstly, we compared posterior estimate of point for first change with the lockdown, which will answer the question whether the lockdown was on time. Secondly, we compared the posterior estimates of consecutive change points to review whether the lockdown was properly implemented. Here, reported days refer to days where COVID-19 cases were registered; therefore, it is different from the length of time interval.

Table 2 presents the date of first COVID-19 infected cases for each of the selected countries, their duration of exposure experienced (days), and number of infected cases reported on dated 11 March 2020, when WHO declared COVID-19 outbreak as a pandemic.

Corresponding to each of the selected countries, duration of exposure experienced (days), and number of infected cases reported on the date scheduled for lockdown, was also presented. In order to visualize the shift in pattern of daily infected cases, for each country, the number of infected cases reported on the posterior estimate of change points, first (Cp 1), second (Cp 2), and third (Cp 3), were also reported. The pattern of daily infected cases and its posterior densities corresponding to each country and their change point were depicted pictorially in Figure S1. The pattern of cumulative COVID-19 cases and its associated deaths was presented in Figure S2.

The country wise change trend for reporting COVID-19 cases are described as follows.

In Russia, the first case of COVID-19 was registered on 31 January 2020, with the first change in trend for reporting COVID-19 cases was posterior estimated as 50th day with 95% CrI (48-52 days), on that day, there was a total of 658 cases registered. Lockdown was scheduled in Russia on the 55th day of reporting, on 31 March 2020, which was the second change point posterior estimate with 95% CrI (54-56 days). The posterior estimate of third change point was observed on 61st days having 95% CrI (60-62 days) with 5389 cases of COVID-19.

In United Kingdom, the first case of COVID-19 was registered on 31 January 2020 and the first change in trend for reporting of COVID-19 cases was posterior estimated as the 49th day with 95% CrI (47-54 days), on that day, there was a total of 2630 cases registered. Lockdown was scheduled in the United Kingdom on 53rd day of reporting cases, on 23 March 2020, The second occasion of change point posterior estimate was on the 56th days (95% CrI, 55-57 days) with reporting of 9529 COVID-19 cases in the country. The posterior estimate of third change point was observed on 62nd days having 95% CrI (61-63 days) with 25 150 cases of COVID-19.

In India, the first case of COVID-19 was registered on 30 January 2020 and the first change in trend for reporting of COVID-19 cases was posterior estimated as 54th day with 95% CrI (49-63 days), on that day, there was a total of 492 cases registered. Lockdown was scheduled in India on same posterior estimated first change point 54th day of reporting on 24 March 2020. The second occasion of posterior estimated change point was on 63rd day with 95% CrI (62-68 days) with reporting of 1397 COVID-19 cases. The posterior estimate of third change point was attained on 68th day having 95% CrI (64-69 days) with 4421 cases of COVID-19.

In France, the first case of COVID-19 was registered on 21 January 2020 and the first change in trend for reporting of COVID-19 cases was posterior estimated as 48th day with 95% CrI (13-60 days), on that day, there was a total of 2281 cases registered. Lockdown was scheduled in France on the 52nd day of reporting on 16 March 2020. The second occasion of change point posterior estimate was on 59th day (95% CrI, 48-77 days) with reporting of 16 018 COVID-19 cases in the country. The posterior estimate of third change point was observed on 64th day having 95% CrI (59-70 days) with 32 964 cases of COVID-19.

In Italy, the first case of COVID-19 was registered on 31 January 2020 and the first change in trend for reporting of COVID-19 cases was posterior estimated as 42th day with 95% CrI (42-44 days), on that day, there was a total of 12 462 cases registered. Lockdown was scheduled in Italy on 40th day of reporting on 10 March 2020, which was 2 days earlier as per the posterior estimate for the first change point on 42nd day. The second occasion of change point posterior estimate was on 49th day (95% CrI, 48-50 days) with reports of 35 713 COVID-19 cases in the country. The posterior estimate of third change point was observed on 60th day having 95% CrI (59-61 days) with 97 689 cases of COVID-19.

TABLE 2 Total numbers of registered COVID-19 cases till the date of lockdown based on duration of exposure and on posterior estimated change point day corresponding to each selected countries

		Total number of registered cases of COVID-19					
Variables		**Russia**	**United Kingdom**	**India**	**France**	**Italy**	**United States**
Date of first case reported		31 January 2020	31 January 2020	31 January 2020	31 January 2020	31 January 2020	31 January 2020
WHO declaration	Cases (day) (11 March 2020)	**10 (35)**	**373 (41)**	**50 (41)**	**1784 (47)**	**10 149 (41)**	**1025 (51)**
Lockdown	Date	31 March 2020	23 March 2020	24 March 2020	16 March 2020	10 March 2020	NA
	Day	55	53	54	52	40	NA
	Cases	**1836**	**5683**	**492**	**5423**	**9172**	NA
Posterior estimated change point	Cp 1 (days)	**658 (50)**	**2630 (49)**	**492 (54)**	**2281 (48)**	**12 462 (42)**	**14 250 (60)**
	Cp 2 (days)	1836 (55)	9529 (56)	1397 (63)	16 018 (59)	35 713 (49)	69 194 (66)
	Cp 3 (days)	5389 (61)	25 150 (62)	4421 (68)	32 964 (64)	97 689 (60)	164 620 (72)

Abbreviations: NA, no complete lockdown was declared in United States.

In the United States, the first case of COVID-19 was registered on 21 January 2020 and the first change in trend for reporting of COVID-19 cases was posterior estimated as 60th day with 95% CrI (59-62 days), on that day, there was a total of 14 250 cases registered. No complete lockdown was declared in United States, as a result on 66th day, the second change point posterior estimate with 95% CrI (65-67 days). The posterior estimate of third change point was observed on 72 days having 95% CrI (71-73 days) with 164 620 cases of COVID-19.

4 | DISCUSSIONS

The WHO on 11 March 2020, had declared the COVID-19 outbreak a global pandemic, pointing to over 100 000 cases of coronavirus and spread across 100 countries and territories around the world. Following the declaration, in a bid to control the spreading of COVID-19 infection, most of the countries implemented lockdown and applied various prohibitions. Lockdown was at the forefront of these restrictions as an emergency protocol that was implemented by the authorities to prevent transmission.

Among the six selected countries, Russia, United Kingdom, and France have delayed in implementing the lockdown, which resulted in increase of infection rate by 3-, 2-, and more than 2-folds, respectively, on the date of declaring lockdown. On comparing the change in pattern of infection rate observed at second point with the first one, it was found that the rate increased by more than 3.5- and 7-folds in United Kingdom and France, respectively. In context of Russia, the second change point and lockdown declaration dates were same. If we compare the third change point in pattern of spreading, then it shows that the infection rates were increase to 8-, more than 9.5-, and 14.5-folds, in Russia, United Kingdom, and France, respectively.

The countries India and Italy were scheduled lockdown either on time or before. Comparing the change in pattern of infection rate observed in these countries at second point with the first one, it was found that the rate increased by about 3-folds, which was comparatively very less than those who delayed. If we compare the third change point in pattern of spreading in these countries, it shows that the infection rates were increased to 9- and 8-folds, respectively, which was again found to be comparatively less. Even on time implementation of lockdown could not help in the virus spreading in both of the countries. Correlating the events[28,29] that occurred during the lockdown in India, the reason for this sudden rise in COVID-19 cases were predominately due to unexpected crowding of migrants in various regions. During that time, individuals' in particular religious groups and low-earning labourers did not follow the restricted measures imposed by the Government in India. The infection might have spread further due to lack of coordination or implementation of lockdown by the concerned authorities to ban public gatherings or individual failure, where infected people unintentionally spread the infection. Similar event[30] occurred in Italy during lockdown and the reason for the rise in COVID-19 cases were mostly due to media leakage of the lockdown on 7 March 2020, which lead to the mass exodus of hundreds of people out of Milan, similar to what was seen in India. The lack of coordination in implementation by the concerned authorities to ban public gatherings and discourage mass movement resulted in a raise in the infection rate.

The lockdown was not completely implemented in the United States, as a result the infection rate increased to 5- and 12-folds, at second and third point, respectively, which was significantly higher than other countries except France.

One of the significant aspects of lockdown was to reduce the burden on health services and arrange proper medical facilities and related infrastructures, to prevent further spread of COVID-19. It was observed from Figure S2 that if the initiative of lockdown was on time and properly maintained then it will not only reduce the spread of COVID-19, but also control its associated deaths by building-up of the medical facilities in time. The impact of Government initiatives and policies, and the effect of failures to control this pandemic can be visualized from the quantum of the severity and time elapsed to death.[31]

5 | CONCLUSIONS

Lockdown is a step towards social distancing to control the spread of this pandemic until availability of any vaccine or anti-viral drugs against COVID-19. The pattern of posterior estimates of change point were compared among six selected countries where lockdown implemented either before (in Italy), or on the day (in India) or after (in Russia, United Kingdom, and France) or not implemented (in the United States). We also explored the reason for the increase in number of daily infected cases of COVID-19 by giving insight into the spread of infections even after lockdown. We correlated the real-life incidences that occurred in the selected countries with the shift or change in pattern of rates of transmission with the duration of exposure. The study suggested that three out of six countries, Russia, United Kingdom, and France, had one of the important reasons for rates of transmission were due to delay in implementing the lockdown. In the study, we also observed that COVID-19-infected cases were increasing in countries where either lockdown was scheduled earlier (Italy) or on the same day (India) to the first change in pattern of rates of transmission observed was most likely due to the system (legislative) failure or individuals' failure or both. In order to control the spreading of COVID-19, lockdown, like other national and international laws, must be obeyed and implemented, which is considered to be a good and safe practice for current outbreak.

The result suggests that on-time decision of lockdown delayed the spreading as observed in the context of India, whereas no lockdown accelerated the infection rate in the United States. Those countries (viz., Russia, United Kingdom, and France) who delayed in implementing lockdown saw their infection cases increased. In order to make effective and protective policy, the researchers' and policymakers must discuss the importance and impact of lockdown to safeguard human life from COVID-19 infection, which can be achieved by following the social distancing and restricting human interaction.

The analysis is no doubt confounded by several variables and has a couple of limitations. The study analysed up to the third change in pattern of transmission rate, and could not be taken into account the changes thereafter. Second, due to the unavailability of information on factors that can explain exposure in private and public, government preparedness and policy actions towards the lockdown, exploration of their association and direct comparison among countries remain unexplored.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS APPROVAL

The database considered for the present study does not contain any individual identifiable information. Due to the unidentified nature of the dataset and no human subject were directly involved in the present study; therefore, this study was exempt from any ethical or Institutional Review Board clearance.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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APPENDIX A.

A change point considered here is the shift occurred due to duration of exposure, such that the number daily registered cases in a country due to COVID-19 follows different distribution before and after that shift. For a given series of COVID-19 daily registered cases in a country till the "*d*" days of exposure, denoted as Y_1, Y_2, …, Y_d a shift or change in point occurs if there exist a "*s*" such that $s \in [1, d-1]$, such that the distributional pattern of $[Y_1, Y_2, \ldots, Y_s]$ and $[Y_{s+1}, Y_{s+2}, \ldots, Y_d]$ are different in context of certain criteria. The criteria chosen is based on duration of exposure, say X_t and error, ε_t denotes the random error, which is assumed to follow normal distribution with mean zero and variance σ^2 such that

$$y_t = \begin{cases} \beta_1 + \beta_2 x_t + \varepsilon_t & 1 < t \le s_j \\ \beta_3 + \beta_4 x_t + \varepsilon_t; & s_j + 1 \le t \le d \end{cases} ;\ \beta_1 \neq \beta_3,\ \beta_2 \neq \beta_4 \tag{A1}$$

The likelihood function based on normal distribution assumption based on the suggested model of Equation (A1) will be

$$L(\mathbf{y}|\mathbf{x},\boldsymbol{\beta},\sigma,s) = \prod_{t=1}^{d} f\left(y_t|\mathbf{x},\boldsymbol{\beta},\sigma,s_j\right) =$$

$$\prod_{t=1}^{s_j}\left(\sqrt{2\pi}\sigma\right)^{-1} e^{-\frac{(y_t-\beta_1-\beta_2 x_t)^2}{2\pi\sigma^2}} \prod_{t=s_j+1}^{d}\left(\sqrt{2\pi}\sigma\right)^{-1} e^{-\frac{(y_t-\beta_3-\beta_4 x_t)^2}{2\pi\sigma^2}} \tag{A2}$$

Under the Bayesian paradigm, the analysis, and characterization of any parameter starts with prior specification corresponding to each of the unknown model parameters. In absence of any prior information about the chosen model parameters, $(\boldsymbol{\beta}, \sigma, s_j)$, where $\boldsymbol{\beta} = \{\beta_1, \beta_2, \beta_3, \beta_4\}$,non-informative priors were suggested. The prior distribution for each of the model parameters are as follows:

$$g(\boldsymbol{\beta}) \propto \text{Constant}; \tag{A3}$$

$$\tau(s_j) \propto t-\text{distribution}\left(\mu = 0, \sigma = \frac{1}{j-1}, df = j-2\right), \tag{A4}$$

$$h(\sigma) \propto \frac{1}{\sigma}, \tag{A5}$$

where, s_j denotes, *j*th of numbers of shifts or change points. For the model simplicity and better understanding of the country-wise variation, we fixed $j = 3$, that is, study focused up to the third change in the pattern of daily registered cases. The joint posterior distribution for the parameters based on the likelihood and prior distributions were derived using Equations (A2) and (3) to (5) will be

$$\varphi\left(\boldsymbol{\beta},\sigma,s_j|\mathbf{y},\mathbf{x}\right) \propto L(\mathbf{y}|\mathbf{x},\boldsymbol{\beta},\sigma,s)g(\boldsymbol{\beta})\tau\left(s_j\right)h(\sigma)$$

$$\propto \sigma^{-d}\exp\left[-\sum_{t=1}^{s}\frac{(y_t-\beta_1-\beta_2 x_t)^2}{2\pi\sigma^2} - \sum_{t=s+1}^{d}\frac{(y_t-\beta_3-\beta_4 x_t)^2}{2\pi\sigma^2}\right], \tag{A6}$$

The marginal posterior distribution of the parameters and its related summaries are obtained through the Markov Chain Monte Carlo simulation procedure[25] using following equations:

$$\varphi(\beta_k|\mathbf{y},\mathbf{x}) \propto \int \varphi\left(\boldsymbol{\beta},\sigma,s_j|\mathbf{y},\mathbf{x}\right)\prod_l d\beta_l d\sigma ds_j; l \neq k, \tag{A7}$$

$$\varphi(\sigma|\mathbf{y},\mathbf{x}) \propto \int \varphi\left(\boldsymbol{\beta},\sigma,s_j|\mathbf{y},\mathbf{x}\right)d\boldsymbol{\beta}ds_j, \tag{A8}$$

$$\varphi\left(s_j|\mathbf{y},\mathbf{x}\right) \propto \int \varphi\left(\boldsymbol{\beta},\sigma,s_j|\mathbf{y},\mathbf{x}\right)d\boldsymbol{\beta}d\sigma. \tag{A9}$$