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Exogenous Parametric Model for the Analysis of the Covid-19 Causalities

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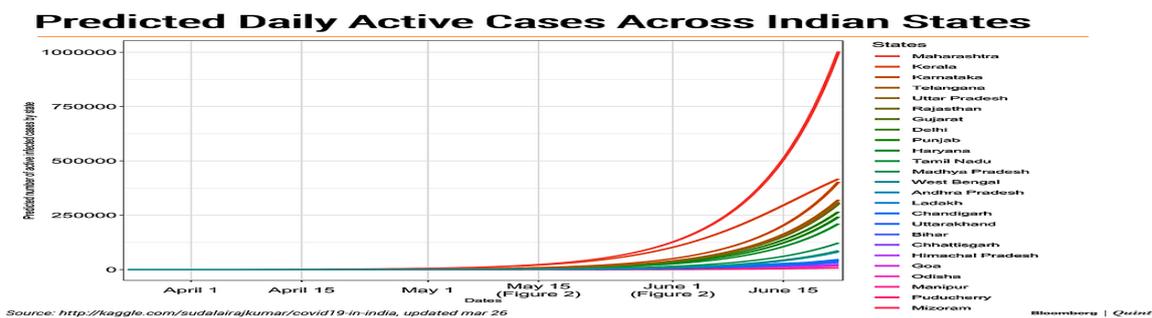
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ABSTRACT: The novel coronavirus (Covid-19) is the main societal concern these days. The virus has distinct effects in different countries. This paper is using the current data of COVID-19 for the mathematical model and analysis. We bring in a new representation to evaluate and manage the outbreak of infectious disease COVID-19 through parametric model considering the exogenous factors such as; growth rate of infectious people as the output and age, travel restrictions, temperature, gender, social distancing and using face mask as the inputs. Parameter estimation was carried out using maximum likelihood estimation method. Numerical results are presented through the appropriate tables and graphs using the data of seven countries.

KEYWORDS: Covid-19, parametric model, infectious, maximum likelihood, exogenous factors.

I. INTRODUCTION

Mathematical formulation of disease models is very effective to understand epidemiological prototypes of diseases, as well as it helps us to take necessary measures of public health intrusions by controlling the spread of the diseases (Pal et.al[6]). In this pandemic, most of the countries had imposed severe intervention measures to control the spread of Covid-19. In early December 2019, the first case of Covid -19 was reported from Wuhan in China and gradually it became the epicentre of the virus. Even though serious measures were being undertaken by the vast majority of countries to contain the outbreak of COVID-19, it is still spreading globally in devastating manner (Kannan et.al [3]). In a widespread, an epidemic follow a similar pattern, the number of infected people gradually increase which shows an exponential behaviour as shown in Fig1.



(Fig1: Exponential curve of the Covid-19 spread, (Source: <https://www.bloombergquint.com/coronavirus-outbreak/covid-19-india-must-urgently-manage-regional-contact-networks>)

Once it reaches the peak, turns over and gradually decreases and fades to zero, marking the end of pandemic. Apart from medical research, mathematical model also helps in making proper decision and the necessary step to stop the spread of Covid-19. According to the study by Chan [1], high temperature at high relative humidity has a synergistic effect on



inactivation of SARS CoV viability while lower temperatures and low humidity support prolonged survival of virus on contaminated surfaces. Another important advisory to stop the spread of Covid -19 was on social distancing and sanitizing. In this paper we are using normal exponential, Covid-19 mathematical model to analyse the transmission dynamics of the virus.

II. EXOGENOUS PARAMETRIC MODEL DERIVATION

Mathematical models generate quantitative information in epidemiology and provide useful guidelines to control the outbreak and in policy development. Quite a few studies have been carried out on Covid -19 using mathematical modelling .For example, Wu et al.[10].derived a SEIR model to explain the transmission dynamics of Covid-19 in China and mentioned that during the period of an epidemic when human-to-human transmission is established and reported case numbers are rising exponentially. Using Poisson distributed assumption, Read et al.[7]. reported a value of 3.1 for the basic reproductive number of the early outbreak. Most of the studies combined mathematical techniques with numerical analysis, data validation and statistical methods have covered a wide range Covid -19 characteristics.Fan et al.[2] developed the SEIR dynamic model of Covid-19 epidemic with incubation period, and predicted the epidemic inflection point through model parameter simulation. Volpert et al.[9] studied a SIR mathematical model to restrict the increase of coronavirus via quarantine procedures. Onder, et al.[5],in his study for Italy and China presented key numbers from the two countries based on the age Covid fatalities. As per the report by Katie Hunt [4],the chance of transmission at a distance of less than 1 meter (3.3 feet) was 12.8%, while that fell to 2.6% at a distance of more than 1 meter (3.3 feet). It added that distances of 2 meters (6.6 feet) could be more effective. It said that the certainty of the evidence was "moderate". The chance of transmission without a face mask or respirator (like an N95 mask) was 17.4%, while that fell to 3.1% when a mask was worn. This paper presents the disease model with normal-exponential distributional assumption to analyse the growth rate of infectious people with the effect of exogenous factors viz., age, travel restrictions, temperature, gender, social distancing and using facemask as the inputs. In the year 2018, authors [8] initiated the derivation of normal exponential exogenous model. p_i is assumed to follow normal distribution as, the normal distribution fits many natural phenomena.

We assume:

$p_i \sim iid N(0, \sigma_p^2)$ and $q_i \sim iid$ exponential, p_i and q_i are the dependent and independent error terms.

Joint density function of p_i and q_i is given by

$$g(p, q) = \frac{1}{\sqrt{2\pi}\sigma_p(\sigma_q + k(x, \eta))} e^{-\frac{p^2}{2\sigma_p^2} - \frac{q}{\sigma_q + k(x, \eta)}}$$

Consider the transformation, $\lambda = p - q$, in the above equation we get,

$$g(q, \lambda) = \frac{1}{\sqrt{2\pi}\sigma_p(\sigma_q + k(x, \eta))} e^{-\frac{1}{2}\left\{\frac{q}{\sigma_p} + \left(\frac{\lambda}{\sigma_p} + \frac{\sigma_p}{\sigma_q + k(x, \eta)}\right)\right\}^2} e^{\frac{1}{2}\left(\frac{2\lambda}{\sigma_q + k(x, \eta)} + \frac{\sigma_p^2}{(\sigma_q + k(x, \eta))^2}\right)}$$

The marginal density function of λ is obtained by integrating $g(q, \lambda)$ with respect to q and is obtained as follows:

$$g(\lambda) = \frac{1}{(\sigma_q + k(x, \eta))} e^{\frac{1}{2}\left(\frac{2\lambda}{\sigma_q + k(x, \eta)} + \frac{\sigma_p^2}{(\sigma_q + k(x, \eta))^2}\right)} \left(1 - \Phi\left(\frac{\lambda}{\sigma_p} + \frac{\sigma_p}{\sigma_q + k(x, \eta)}\right)\right)$$

The Likelihood function for the product of N sample is obtained from

$$L = \prod_{i=1}^N g(\lambda_i)$$

Using the first order conditions of the maximization of log-likelihood function we get,



$$\frac{\partial \ln L}{\partial \sigma_p^2} = \frac{1}{2} \sum_{i=1}^N \frac{1}{(\sigma_q + k(x, \eta))^2} + \frac{\sum_{i=1}^N \phi\left(\frac{\lambda}{\sigma_p} + \frac{\sigma_p}{\sigma_q + k(x, \eta)}\right)}{\sum_{i=1}^N \Phi\left(\frac{\lambda}{\sigma_p} + \frac{\sigma_p}{\sigma_q + k(x, \eta)}\right)} \left(\frac{-\lambda}{2\sigma_p^3} + \frac{1}{2\sqrt{\sigma_p}(\sigma_q + k(x, \eta))} \right)$$

$$\frac{\partial \ln L}{\partial \beta} = \frac{-z_i}{\sigma_q + k(x, \eta)} - \frac{z_i}{\sigma_p} \frac{\sum_{i=1}^N \phi\left(\frac{(y_i - \beta z_i)}{\sigma_p} + \frac{\sigma_p}{\sigma_q + k(x, \eta)}\right)}{\sum_{i=1}^N \Phi\left(\frac{(y_i - \beta z)}{\sigma_p} + \frac{\sigma_p}{\sigma_q + k(x, \eta)}\right)}$$

Point estimation of the model is obtained as,

$$E(q / \lambda) = \int_0^\infty q g(q / \lambda) dq, \text{ where } f(q / \lambda) = \frac{1}{\sigma_p \sqrt{2\pi}} \left(1 - \Phi\left(\frac{\hat{\varpi}}{\sigma_p}\right) \right)^{-1} e^{-\frac{1}{2} \left(\frac{q + \hat{\varpi}}{\sigma_p} \right)^2}$$

On further simplification to find the growth rate of virus with the exogenous variable considered in the study is obtained as given below;

$$E(q / \lambda) = \frac{\phi\left(\frac{\hat{\varpi}}{\sigma_p}\right) \sigma_p}{1 - \Phi\left(\frac{\hat{\varpi}}{\sigma_p}\right)} - \hat{\varpi} \quad (1)$$

The effect of each exogenous variable on growth rate can be calculated from $\frac{\partial E(q_i / \lambda_i)}{\partial k_i}$ after the

calculation of each countries efficiency to control the pandemic.

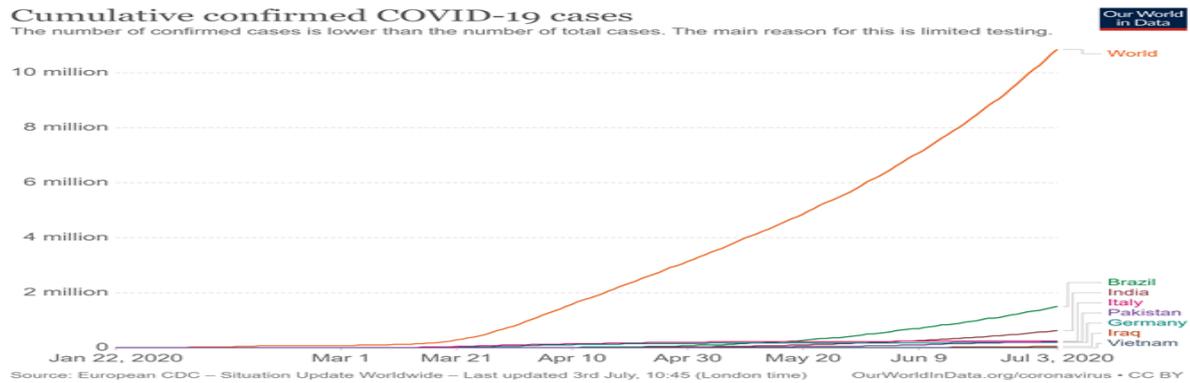
Mathematical representation of disease model for the influencing factors on Infectious rate is given by,

$$I_i(t) = \varpi_0 + \varpi_1 b_{1i} + \varpi_2 b_{2i} + \varpi_3 b_{3i} + \varpi_4 b_{4i} + \varpi_5 b_{5i} \quad (2)$$

where b_{1i} is age, b_{2i} is travel restrictions, b_{3i} is temperature, b_{4i} is gender, b_{5i} is social distancing and using face mask.

III. NUMERICAL SIMULATION AND JUSTIFICATION OF RESULT

In this section, we fit our proposed disease model to the data collected from seven countries viz., Brazil, Italy, India, Vietnam, Germany, Pakistan and Iraq. Data are collected from the official website of WHO and statistical departments. We first estimated each countries efficiency to control the pandemic using model (1). Simulation work was carried out using LIMDEP 11 software. Since the paper is focusing on the influencing factors on infectious rate, results are discussed on the same. Fig 2 shows the confirmed Covid-19 cases in the world and the countries under study as of July 4th 2020. The infection rate of the countries under study to the world rate stands as follows; Brazil-13.9%, Italy- 2.17%, India-6.06%, Vietnam-0.003%, Germany-1.77%, Pakistan-2.03%, Iraq-0.50%.



(Fig 2 Confirmed Covid -19 cases in the countries selected for the study, Source: <https://ourworldindata.org/mortality-risk-covid>)

While selecting the countries for the study, countries with high and low fatality rate were considered. Under the influencing Covid -19 factor age fatality rate is depicted in Fig3. Average temperatures of the countries under study was used to explore the association between Covid-19 infections and weather parameters as in Fig4. Following the outbreak of corona virus governments around the world imposed travel ban. It is difficult to calculate exactly the level of traffic reduction imposed hence this parameter is measured in months starting from April.

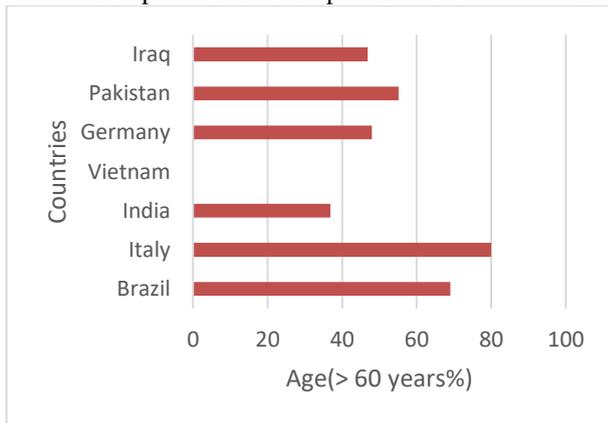


Fig 3-Covid -19 Case fatality by age

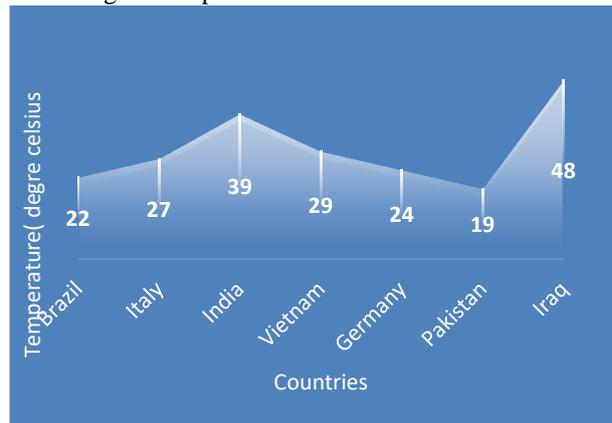


Fig 4 Temperature of the countries under study

Social distancing pattern followed by Brazil, Pakistan, Vietnam and Iraq was 1m; 1.5m by Germany and Italy. India followed a 2m distance. Face mask was made mandatory in all the countries. Fatality rate by gender showed that overall number of infected men is higher except in Vietnam. Table1 presents the summary statistics of the variable along with the units of measurements.

Variables	Mean	Std.Dev	Minimum	Maximum
Age (ϖ_{1i}) (%)	48	25.6	0	80
Travel restrictions (ϖ_{2i})(Months)	1.85	0.69	1	3
Temperature (degree Celsius) (ϖ_{3i})	29.7	10.29	19	48
Social Distancing (m) and face mask (ϖ_{5i})	1.29	0.39	1	2

Table 1 Summary statistics of the variable under study

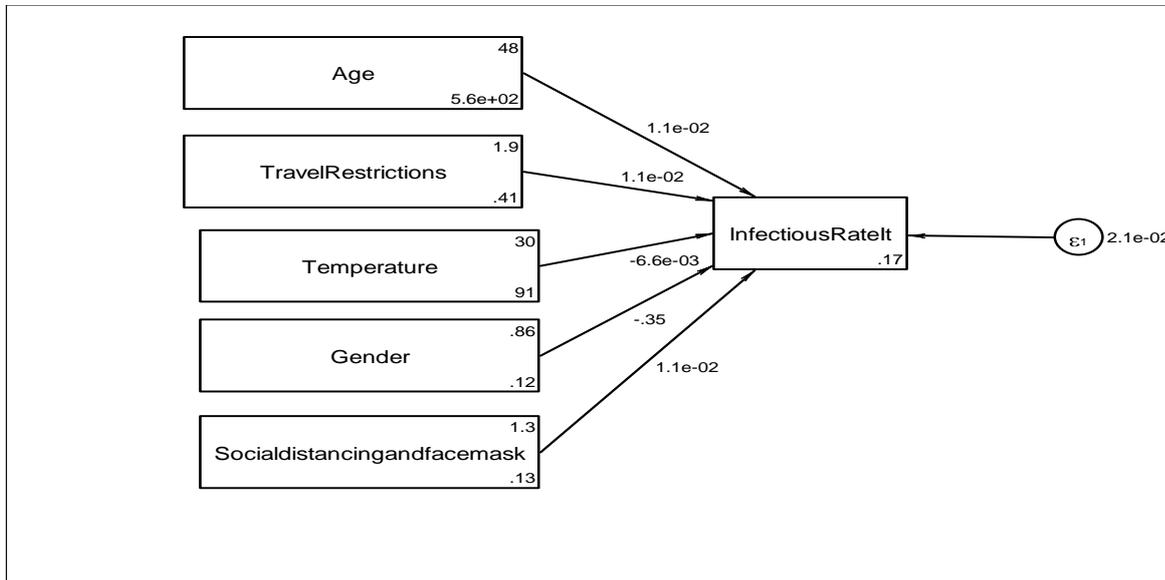


Fig 5. Disease model for the influencing factors of Infectious rate.

Disease model results shows that variables age, travel restrictions social distancing and face mask have positive coefficients, indicating that these variables can significantly affect the case fatality rate if proper care is not taken. Among the aged people, the risk of illness from Covid-19 is higher with most of them having underlying medical conditions. Negative sign on the coefficients of temperature and gender reveals that, these two factors doesn't have any significant role in the increase of infection rate. Maximum likelihood estimate of the variables under study are presented in Table 2 which shows that age, travel restrictions, social distancing and face mask can significantly affect the infection rate with p value less than 0.05, whereas, temperature and gender were insignificant with p values greater than 0.05.

Variables	Coefficient	Std. Error	P value
Constant	0.171	0.288	0.5
Age (ϖ_{1i})	0.011	0.004	0.032
Travel restrictions (ϖ_{2i})	0.011	0.0032	0.03
Temperature (ϖ_{3i})	-0.006	0.007	0.354
Gender ϖ_{4i}	-0.002	0.0074	0.355
Social Distancing and Face mask ϖ_{5i}	0.011	0.0035	0.0033

Table 2 Maximum likelihood estimate of the disease model under study

Hence the mathematical representation of disease model for the influencing factors on Infectious rate is given by,

$$I_i(t) = 0.171 + 0.11b_{1i} + 0.011b_{2i} + (-0.006)b_{3i} + (-0.345)b_{4i} + (0.011)b_{5i}$$

IV. CONCLUSION

In this paper we have formulated a mathematical model to analyse the infectious rate of COVID-19 virus which is transferred from human to human. We considered the countries with highest and lowest mortality rate. Depending on the population of the countries under study the mortality rate of some countries seems to be under control with the Government's ongoing measures. Still the cases are increasing far day by day. Hence the factors that increase the infectious rate has to be identified and controlled. Seeing the exponential characteristic of the infection growth, we have developed a disease model with normal exponential distribution to identify the factors that trigger the infection in the selected countries. Result reveal that age of the patient play a major role in increasing the mortality rate. We see that parameter ϖ_{1i} (0.011), ϖ_{2i} (0.011), ϖ_{5i} (0.011) have positive coefficients indicating the positive contribution of the variables to the increase of Covid-19 cases. Study doesn't support that hot or cold temperature (ϖ_{3i} , -0.006), being male or female (ϖ_{5i} , -0.345) can increase the infection rate with its negative coefficients. Government is continuously changing its restricting measures to stop the spreading of COVID-19. Continuing with travel restrictions, social distancing and facemask norms can help in controlling the spread of Covid-19. Apart from government individuals have to take care of themselves and the society by abiding with the safety and precautionary measures issued by government and WHO as per the model. Further in this paper only few factors are considered for the study . Future research can be combined with artificial intelligence to make policy suggestions.

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