Effect of Step by Step Plan over the effective reproductive number of COVID-19 in Chile

Leonardo Jofré[1], Inés Varas[2], Luis Gutiérrez[1], Iván Gutiérrez[1], Oscar Ortiz[3], Jaime Cerda[4], Jessica Pavani[1], Danilo Garrido[1], and Gabriel Arriagada[3]

[1] *Faculty of Mathematics, Department of Statistics, Pontificia Universidad Católica de Chile*
[2] *Millennium Nucleus Center for The Discovery of Structures in Complex Data (MiDaS)*
[3] *Institute of Agri-food, Animal and Environmental Sciences, Universidad de O'Higgins*
[4] *Faculty of Medicine, Department of Public Health, Pontificia Universidad Católica de Chile*

Resumen

In the development of a pandemic, it is important to quantify the transmissibility of the disease to detect changes over time, as well as to evaluate the effect of the sanitary measures that are determined to control the spread of the disease. In this context, in Chile the Step by Step Plan (Plan Paso a Paso its Spanish name) was established which gradually restricts the mobility of people at the commune level, the smallest geographic and administrative area in the country. A spatio-temporal model is proposed for the dynamic of weekly COVID-19 infections in Chile at the commune level which allows to estimate the effective reproductive number of COVID-19 and the effect of the different phases of the Step-by-Step Plan over it. The results indicate that the phases with higher are useful to keep the effective reproductive number under 1, on average.

1. Introduction

To understand the dynamics of the disease in the development of a pandemic and to evaluate the effectiveness of sanitary measures adopted is essential for the generation of public policies aimed to control the spread of the disease. In the context of the COVID-19 pandemic, different methodologies to estimate the effective reproductive number (R_t) which allows to quantify the transmission of viral disease. In addition, different measures have been established to control the spread of the disease, including non-pharmacological measures such as the Step by Step Plan. This plan consists on the establishment of 4 different levels of mobility and social distance restrictions for people at the commune level. Some international studies have evaluated the effect of quarantine on new cases of COVID-19 (see Nussbaumer-Streit et al. [2020] and Arriagada et al. [2021]), however there are no studies that quantify the effect of the Step by Step plan on the containment of the pandemic in Chile. In this study, a methodology is proposed based on a spatio-temporal model for the dynamics of infections, considering the information from the Step-by-Step plan over time. The dynamics of the effective reproductive number of COVID-19 in Chile can be estimated at the communal level with the proposal.

2. Goal

The main goal of this study was to evaluate the effect of the Step by Step plan over the effective reproductive in Chile at commune level.

3. Methodology

The study considered a retrospective design based on the number of new cases of COVID-19 in Chile weekly (epidemiological ween) between March 2020 to July 2021 for the 345 communes of the country (the Antarctic territory is excluded). In addition, the information from the stage of the Step by Step Plan in the epidemiological week for each commune is used. The Step-by-Step Plan includes Phase 1: Quarantine, Phase 2: Transition, Phase 3: Preparation, Phase 4: Initial Opening.

Cori et al. [2013] propose that the effective reproductive number R_t can be approximated as the ratio between the current new cases at time t, I_t, and a convex combination of past infected (possible primary infected), i.e.,:

$$R_t \;=\; \frac{I_t}{\sum_{s=1}^{t} \omega_s I_{t-s}}, \tag{1}$$

where the weights $\omega_1, \ldots, \omega_t$ define the infectious profile of the disease, which only depends on the characteristics of the disease. Thus, if $\mathscr{F}_{t-1}$ represents the information on new infections up to time $t-1$, then $E(I_t \mid \mathscr{F}_{t-1}) = R_t \sum_{s=1}^{t} I_{ts} w_s$.

Given the spatial nature of disease dynamics, it is important to consider spatial correlation of new cases of COVID-19 when modeling. Besag et al. [1991] propose a model with ICAR effect (Intrinsic Conditional Auto-Regressive model), which allows to incorporate dependence of observations on neighboring geographic units and a random effect to quantify non-spatial variability. This proposal has been widely used in epidemiological models (see Lawson [2018]).

Based on the result (1), a hierarchical model is proposed that considers the spatio-temporal structure of the number of new cases of COVID-19 at the communes of Chile. For the 345 communes of the country and for each epidemiological week, let us denote by I_{ij} the number of new cases for the commune i in the epidemiological week j and $\mathscr{F}_{i,j-1}$ the information on new cases in the commune i up to the epidemiological week $j-1$. Based on the proposal of Cori et al. [2013], a hierarchical Poisson model is proposed for the number of new cases of COVID-19, indexing the effective R by fixed and random effects considering the geospatial structure proposed by Besag et al. [1991]. The estimation of the model is carried out from a Bayesian approach considering the following structure:

$$\begin{aligned}
I_{ij} \mid \boldsymbol{\beta}, \phi, u, \boldsymbol{w}, \mathscr{F}_{i,j-1} &\overset{iid}{\sim} \mathscr{P}ois(\mu_{ij}), \\
\mu_{ij} &= R_{ij} \sum_{s=1}^{k} \omega_s I_{t-s}, \\
R_{ij} &= \exp(\boldsymbol{x}'_{ij}\boldsymbol{\beta} + \phi_i + u_i), \\
\boldsymbol{\beta} &\sim \mathscr{N}_q(\mathbf{0}, \sigma^2_{\beta} I_q), \\
\boldsymbol{\phi} &\sim \mathscr{N}_m(\mathbf{0}, [\boldsymbol{D} - \boldsymbol{W}]^{-1}), \\
\boldsymbol{u} &\sim \mathscr{N}_m(\mathbf{0}, \tau^2 I_m), \\
\boldsymbol{w} &\sim Dirichlet(a_1, \ldots, a_k),
\end{aligned} \tag{2}$$

where $\boldsymbol{x}'_{ij}$ is the vector of fixed effects (considering the information of the Step by Step Plan phase), $\boldsymbol{\beta}$ is the vector of parameters of the fixed effects, ϕ_i is the ICAR component, u_i is the random intercept for the commune and $\boldsymbol{w}$ represents the infectious profile of the COVID-19 disease. The implementation of the model is done in Stan (Stan Development Team [2020]) using the implementation of the model Besag et al. [1991] in this software (Morris et al. [2019]).

The sources of information used for this study are the records of new cases (file p15_new_cs) and the information of the Step-by-Step Plan registered in the files p29_cuarantine (communal quarantines) and p74_pap_dc (Step by Step Plan at commune level). For more details on the construction of the data sources, see Ortiz et al. [2021].

4. Results

Considering the information on new cases of COVID-19 in Chile and the information of the Step-by-Step Plan at commune level from the epidemiological week 10 of 2020, it is observed that Phase 1 of quarantine is the phase that tends to decrease the most the effective R value (see Table 1). In Table 2 is summarized the mean of the effective R estimated for each phase of the plan. For the phases 3

Tabla 1: Estimated parameters for the phases of Step by Step plan considering information from march 2020 to july 2021.

Parameter	**Mean**	**95 % Credible interval**
Phase 1: Quarantine	-0.3056	(-0.3076 ; -0.3035)
Phase 2: Transition	-0.1947	(-0.1976 ; -0.1916)
Phase 3: Preparation	-0.0761	(-0.081 ; -0.0713
Phase 4: Initial Opening	0.1489	(0.1475 ; 0.1505)

Tabla 2: Mean of effective R estimated for the phases of Step by Step plan considering information from march 2020 to july 2021.

Effective R	**Mean**	95 % Credible interval
Phase 1: Quarantine	0.8550	(0.8529; 0.8573)
Phase 2: Transition	0.9554	(0.9523 ; 0.9586)
Phase 3: Preparation	1.0754	(1.0702 ; 1.0812)
Phase 4: Initial Opening	1.1606	(1.1589 ; 1.1624)

and 4 (Preparation and Initial Opening, respectively), the 95 % credible interval is up to 1, while for phases 1 and 2 (Quarantine and Transition, respectivvely) this interval is under the value 1.

To illustrate the results obtained in this study, Figure **??** shows the evolution of new cases for the commune of Calama throughout march 2020 to july 2021. The figure also shows new cases predicted by the model and the effective R value. In colors, the effective R associated with the phase of the Step by Step Plan is shown during the study period, with a lag of two weeks. It is observed that at the end of phases with less restrictions in people's mobility (Phase 3 and 4), the cases tend to increase, while in phases of more restrictions, the dynamics of new cases tends to decrease.

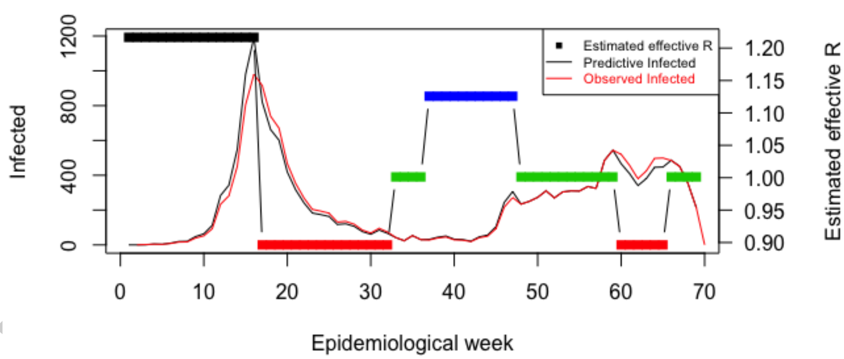

Figura 1: New cases of COVID-19 dynamics and estimation of the effective R for the commune of Calama, Region of Antofagastaa, between march 2020 to july 2021. The Step by Step Plan phase is shown in colors: Phase 1-Quarantine (red), Phase 2-Transition (green), Phase 3-Preparation (blue) and Phase 4-Initial Opening (black).

Given that the proposed model allows to estimate the value of the effective R at commune level, the figure 2 shows the value of the effective R for the communes of Region of the Antofagasta in each of the phases of the Step by Step plan. It is observed that, as the phases of the plan are less restrictive, the value of the effective R for most of the communes in the region tends to be up the threshold of 1.

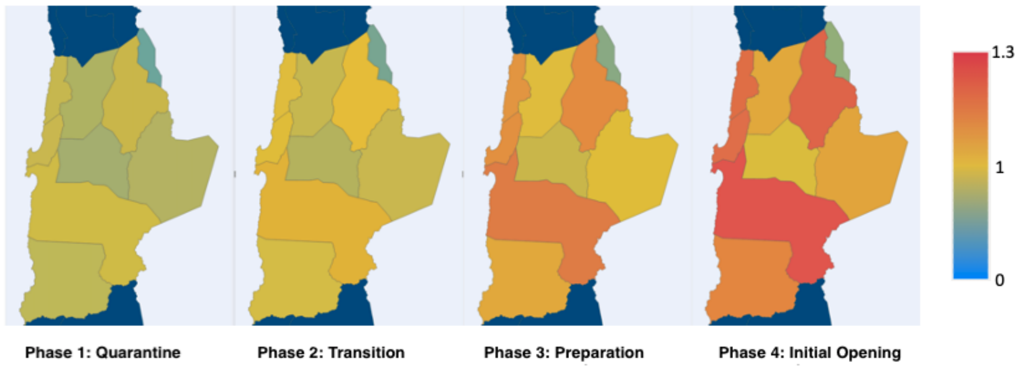

Figura 2: Estimated effective R for communes in the region of Antofagasta.

5. Preliminary conclusions

The results of this study indicate that there is an effect of the Step-by-Step Plan on the effective R: the quarantine phase and the transition phase are useful to keep the average effective R to be controlled under the value 1. As the Step by Step plan is less restrictive (from phase 3 onwards), this value exceeds the threshold of 1, on average. In addition, with the proposed methodology, the effectiveness of the Step by Step Plan can be quantified for each commune, indicating which ones have better or worse performance to the restrictive measures.

Referencias

G. Arriagada, L. Jofré, I. M. Varas, D. Garrido, O. Ortiz, I. Gutiérrez, J. Pavani, J. Cerda, and L. Gutiérrez. Evaluacióon del efecto de las cuarentenas sobre la dinámica espacio-temporal de covid-19 en chile. https://epicovid.cl/, 2021. URL https://epicovid.cl/.

Julian Besag, Jeremy York, and Annie Mollié. Bayesian image restoration, with two applications in spatial statistics. *Annals of the Institute of Statistical Mathematics*, 43(1):1–20, 1991.

Anne Cori, Neil Ferguson, Christophe Fraser, and Simon Cauchemez. A new framework and software to estimate time-varying reproduction numbers during epidemics. *American Journal of Epidemiology*, 178, 09 2013.

Andrew B Lawson. *Bayesian disease mapping: hierarchical modeling in spatial epidemiology*. Chapman and Hall/CRC, 2018.

M. Morris, Katherine Wheeler-Martin, Daniel P. Simpson, S. Mooney, A. Gelman, and C. DiMaggio. Bayesian hierarchical spatial models: Implementing the Besag York Mollié model in stan. *Spatial and Spatio-temporal Epidemiology*, 31:100301, 2019.

B. Nussbaumer-Streit, V. Mayr, Dobrescu A. I., E. Chapman A., Persad, I. Klerings, G. Wagner, U. Siebert, C. Christof, C. Zachariah, and G. Gartlehner. Quarantine alone or in combination with other public health measures to control covid-19: a rapid review. *The Cochrane database of systematic reviews*, 4, 2020.

Oscar Ortiz, Danilo Garrido, Gabriel Arriagada, Luis Gutiérrez, Jaime Cerda, Jessica Pavani, Leonardo Jofré, Inés Varas, and Iván Gutiérrez. Base de datos epidemiologica y sociodemográfica COVID-19 en Chile y el mundo. https://epicovid.cl/, 2021. URL https://epicovid.cl/.

Stan Development Team. RStan: the R interface to Stan, 2020. URL http://mc-stan.org/. R package version 2.21.2.