Estimation and optimal control of the multi-scale dynamics of the Covid-19

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Abstract

This work aims at a better understanding and the optimal control of the spread of the new severe acute respiratory corona virus 2 (SARS-CoV-2). We first propose a multi-scale model giving insights on the virus population dynamics, the transmission process and the infection mechanism. We consider 10 compartments in the human population in order to take into accounts the effects of different specific mitigation policies. The population of viruses is also partitioned into 10 compartments corresponding respectively to each of the first nine human population compartments and the free viruses available in the environment. We show the global stability of the disease free equilibrium if a given threshold T_0 is less or equal to 1 and we provide how to compute the basic reproduction number R_0. A convergence index T_1 is also defined in order to estimate the speed at which the disease extincts and an upper bound to the time of extinction is given. The existence of the endemic equilibrium is conditional and its description is provided. We evaluate the sensitivity of R_0, T_0 and T_1 to control parameters such as the maximal human density allowed per unit of surface, the rate of disinfection both for people and environment, the mobility probability, the wearing mask probability or efficiency, and the human to human contact rate which results from the previous one. Except the maximal human density allowed per unit of surface, all those parameters have significant effects on the qualitative dynamics of the disease. The most significant is the probability of wearing mask followed by the probability of mobility and the disinfection rate. According to a functional cost taking into consideration economic impacts of SARS-CoV-2, we determine and discuss optimal fighting strategies. The study is applied to real available data from Cameroon and an estimation of model parameters is done. After several simulations, social distancing and the disinfection frequency appear as the main elements of the optimal control strategy.

Full Text

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Figures

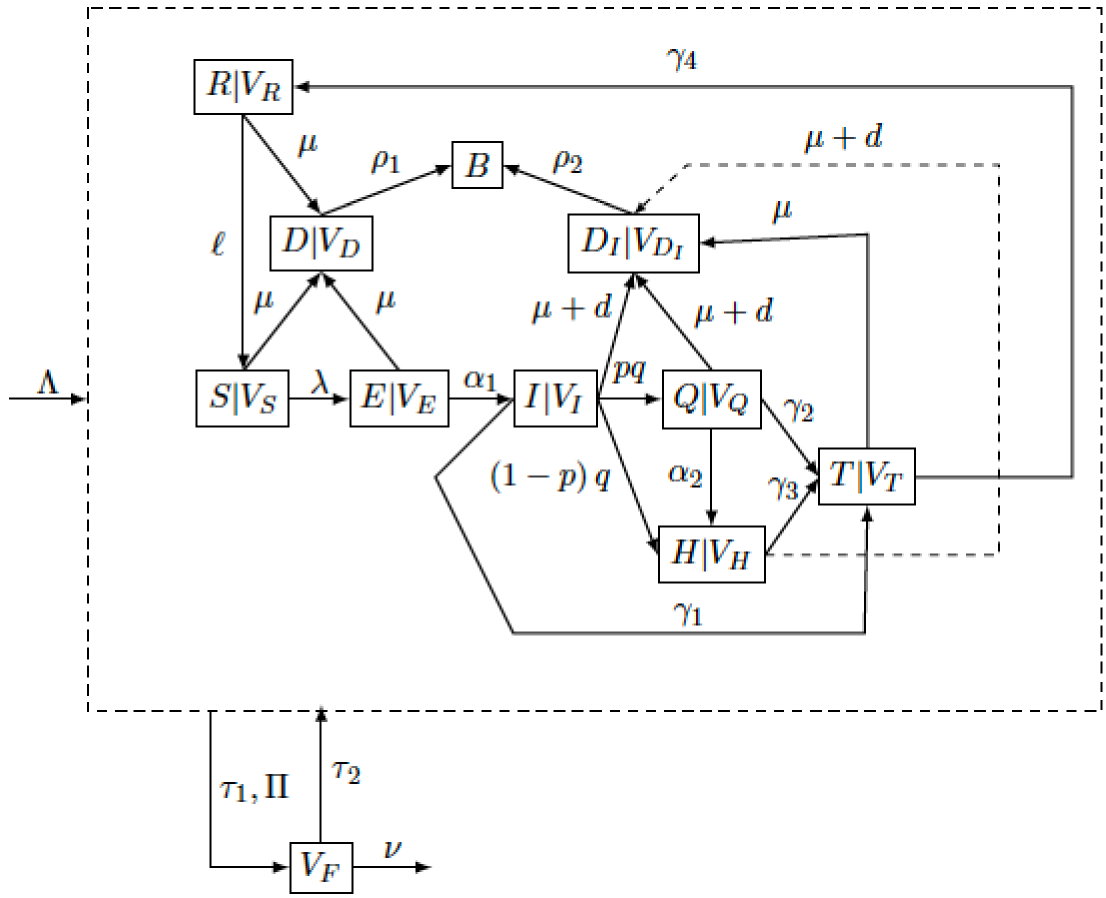
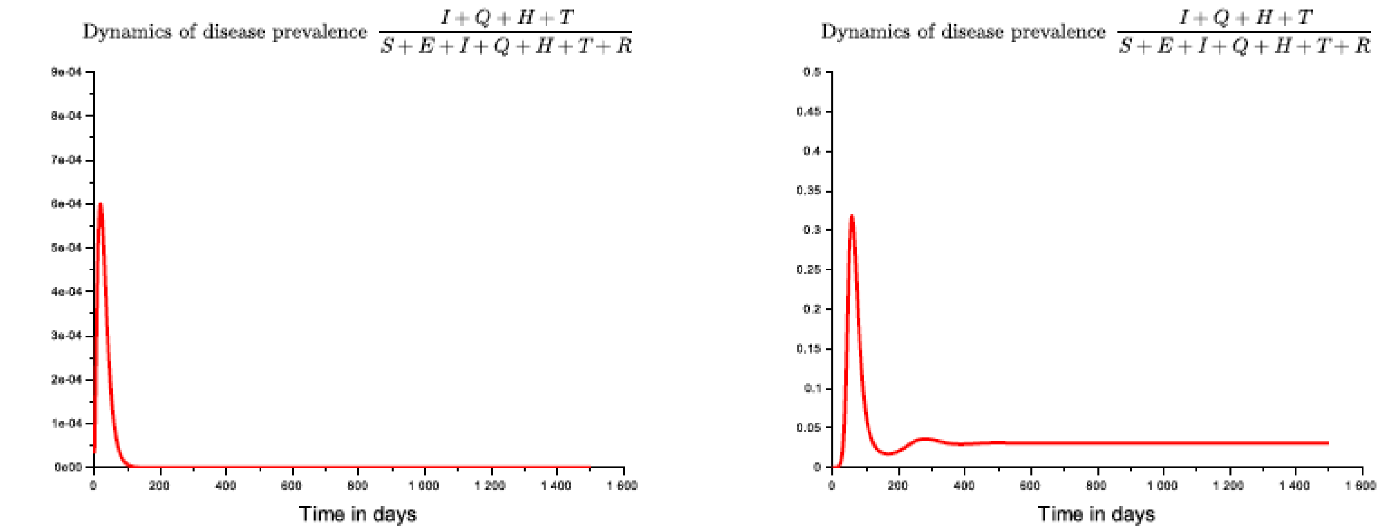


Figure 1

Flow chart of the Susceptible (S)- Exposed (E)- Infectious (I)- Quarantined (Q)- Hospitalized (H)- Treated (T)- Recovered (R)- Non Infectious Dead (D)- Infectious Dead (DI)- Buried (B) compartmental model with corresponding viruses subpopulations (Vk; k 2 fS;E; I; Q;H; T;R;D;DIg) and free viruses in the environment (VF)



$(a)\ \kappa = 0.35\ person \times m^{-2},\ \omega_i = 24 \times hour^{-1},$
$i = 1, \ldots, 7,\ \omega_8 = \omega_9 = \omega_{10} = 0 \times day^{-1}$
$u_i = m_i = 0.5, i = 1, \ldots, 10,\ \mathscr{T}_0 = 4.4717 \times 10^{-2}$
$\mathscr{R}_0 = 7.5113 \times 10^{-3}$

$(b)\ \kappa = 8\ person \times m^{-2},\ \omega_i = 0 \times day^{-1}$
$, i \in \{1, 2, 3, 6, 7\}\ u_i = m_i = 0, i = 1, \ldots, 10,$
$\mathscr{T}_0 = 44791.419,\ \mathscr{R}_0 = 107.59773$

Figure 2

Asymptotic behavior of infectious dynamics depending on T0

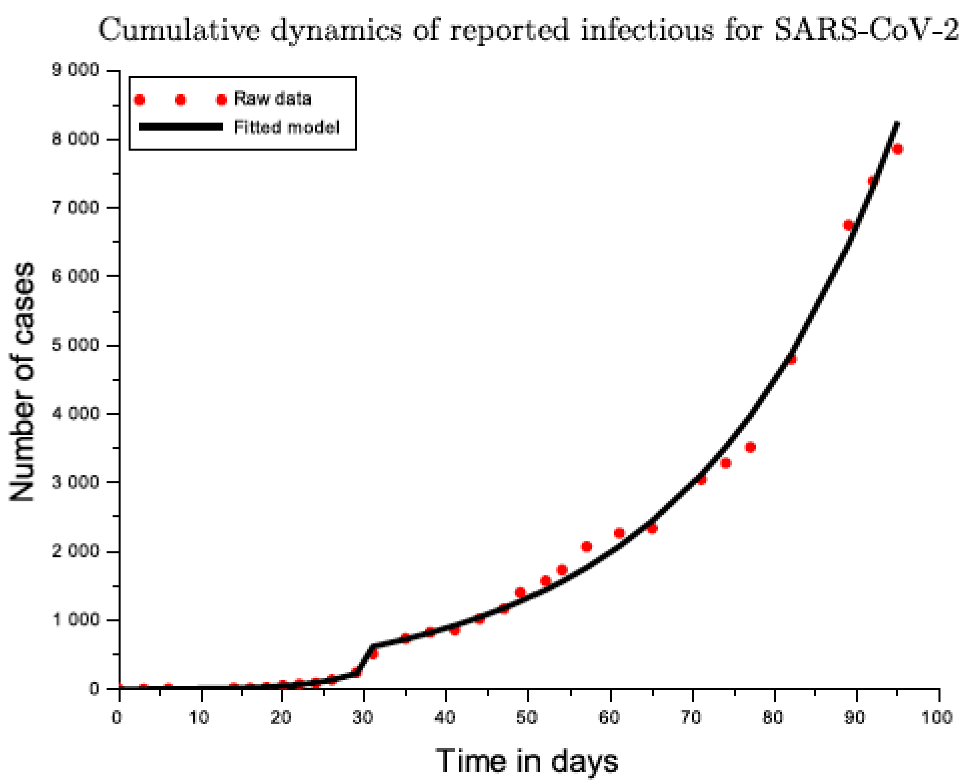


Figure 3

Cumulative reported infectious from the 2nd of March to the 07th of June 2020.

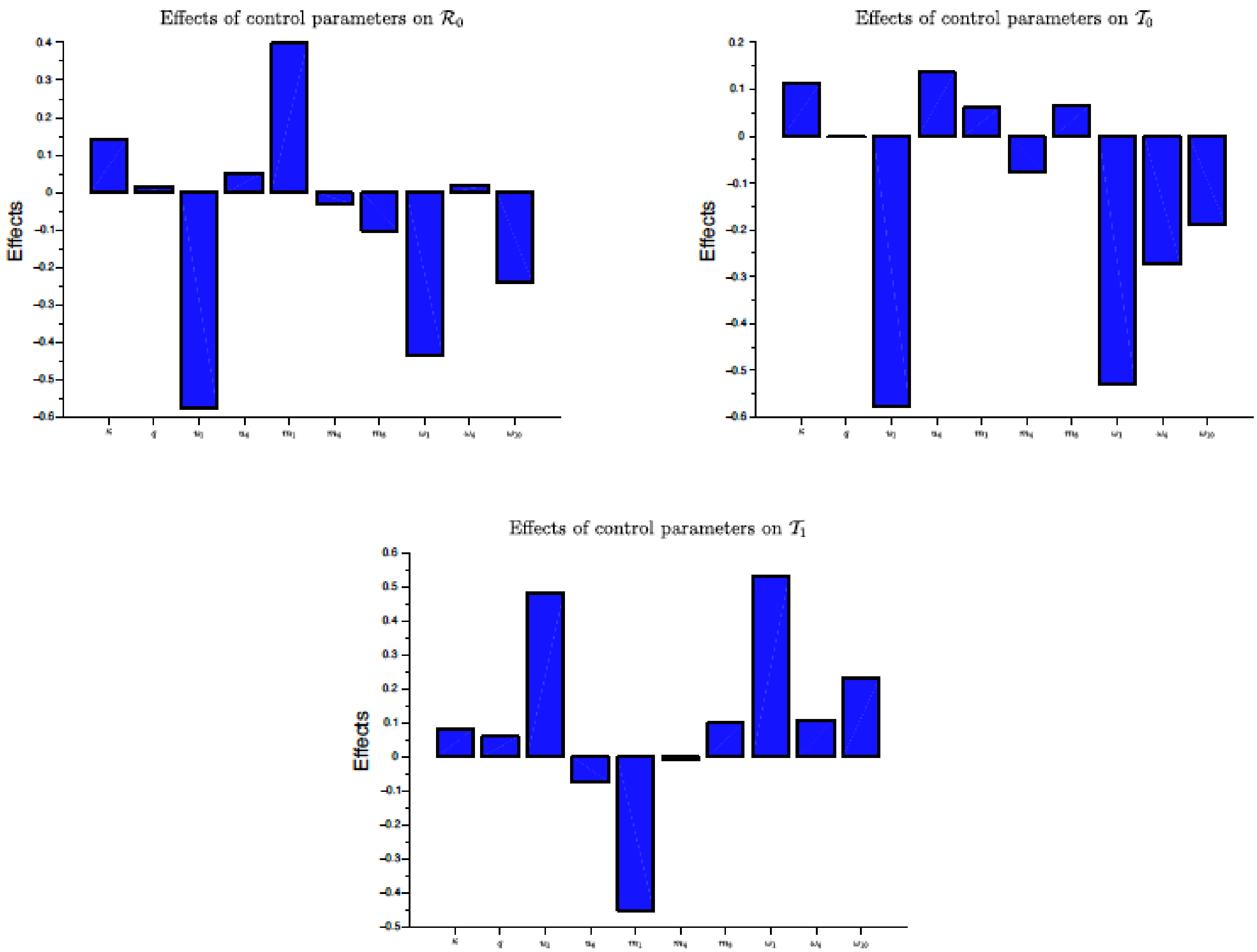


Figure 4

Effects of control parameters on R0, T0 and T1

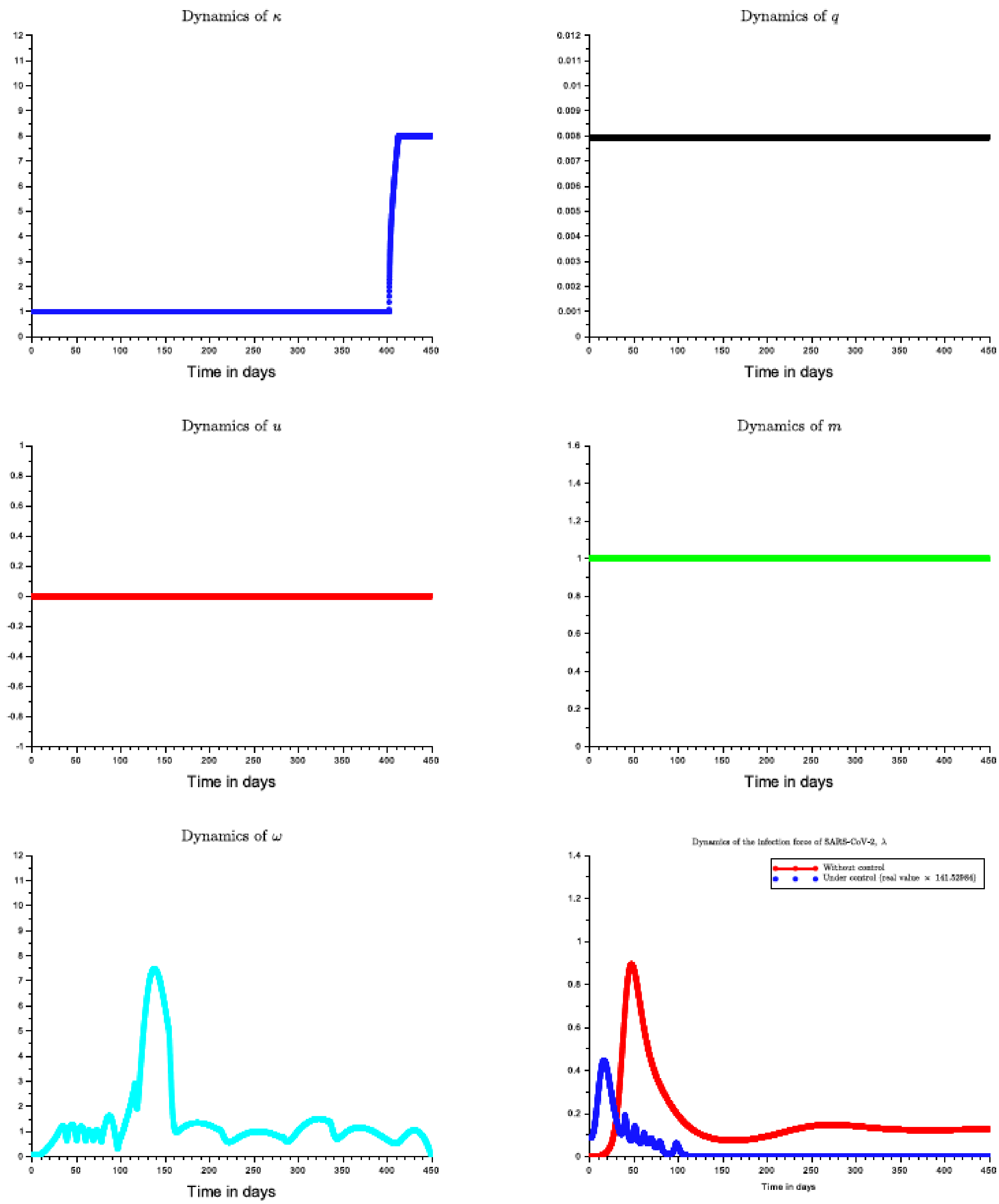


Figure 5

Optimal control dynamics of Covid-19 prevalence

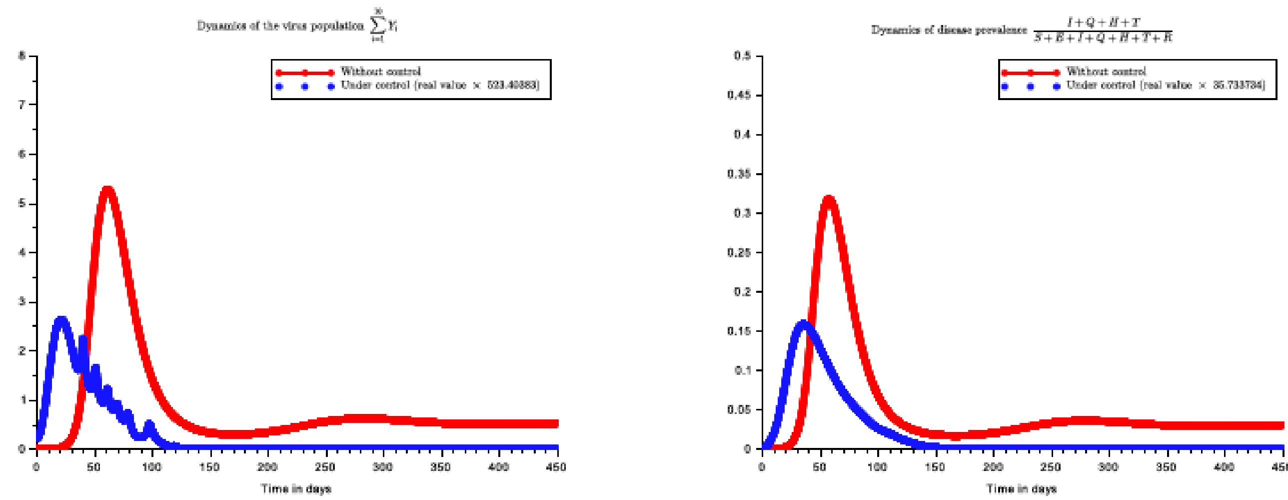


Figure 6

Controlled dynamics of Covid-19 prevalence