Parameter estimation and validation against Wuhan data

The initial conditions are set according to the reported situation in Wuhan at the beginning of the outbreak:

$$\begin{aligned} &S(0) = 11\,000\,000,\ E(0) = 1000,\ I(0) = 500,\ V(0) = 0, \\ &R(0) = 0,\ H(0) = 0,\ D(0) = 0. \end{aligned} \tag{1}$$

Here, the susceptible population is initialized close to the total population of Wuhan; in contrast, a small number of exposed and infected individuals is assumed to represent the early phase of disease transmission. Since vaccination was not available at the beginning of the outbreak, the initial vaccinated population is set to zero. Similarly, the recovered, heart attack, and deceased classes are initially taken as zero. The recruitment rate is also defined as:

$$\Lambda = \mu N(0), \tag{2}$$

which ensures that, in the absence of infection-related mortality and disease transmission, the population remains approximately constant. The remaining epidemiological and clinical parameters are selected from the literature or estimated by nonlinear least-squares fitting to cumulative confirmed COVID-19 cases in Wuhan. The fitted transmission rate is $\beta = 0.48\ day^{-1}$, which reflects the relatively high transmissibility of COVID-19 during the early stage of the outbreak. The full set of parameter values used in the simulations is reported in Table 1. The estimated parameters generate epidemic trajectories that are consistent with the expected outbreak pattern: in the absence of control, the susceptible population decreases rapidly, the exposed and infected classes increase sharply during the middle phase of the epidemic, and the recovered and deceased populations accumulate over time. This confirms that the uncontrolled model can reproduce the principal qualitative features of COVID-19 transmission dynamics. After this validation step, the optimal control framework is applied to determine whether a coordinated intervention policy can reduce infection, cardiac complications, and mortality.

Table 1: Default parameter values for the mathematical model for the effect of COVID-19 on heart attack risk.

Parameter	Description	Value	Unit
β	COVID-19 transmission rate	0.48	day^{-1}
ε	Infection rate of individuals exposed to COVID-19 disease	0.25	day^{-1}
γ	Recovery rate of individuals with COVID-19 disease	0.1	day^{-1}
μ	Natural death rate of patients	0.00004	day^{-1}
α	Rate of heart attack incidence due to infection	0.025	day^{-1}
δ	Rate of heart attack treatment due to COVID-19 complications	0.07	day^{-1}
ρ	Vaccine efficacy in reducing individuals susceptible to COVID-19 disease	0.85	-
κ	Vaccine efficacy in reducing progression to severe infection and heart attack risk	0.80	-
θ	Mortality rate due to infection or heart attacks	0.02	day^{-1}
Λ	Constant recruitment (birth) rate into the susceptible class	440	day^{-1}