Sustainable social distancing through facemask use and testing during the Covid-19 pandemic

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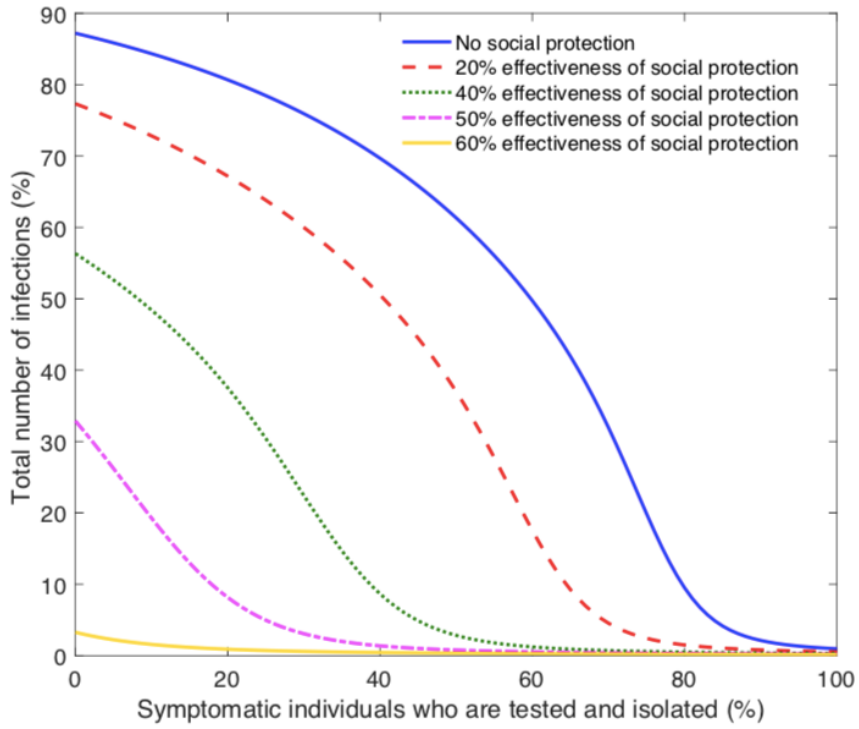
Recent reports have documented substantial proportions of asymptomatic or mildly symptomatic Covid-19 infections that may also be infectious [1-3] as well as the potential role of respiratory droplets and contaminated surfaces in driving SARS-CoV-2 transmission [4]. While facemask use is promoted in healthcare settings as part of infection control protocols [5-8], its use during the COVID-19 pandemic varies across countries [9,10]. As the COVID-19 pandemic rages on, widespread facemask use has been recently recommended by Dr. George Gao, the director-general of the Chinese Center for Disease Control and Prevention (CDC) [11].

Any plan for stopping the ongoing 2019-nCov pandemic must be based on a quantitative understanding of the proportion of the population that needs to be protected by effective control measures such that each infected person infects no more than one other person on average (the effective reproductive number, $R < 1$), at which point transmission contracts and eventually burns out. Based on a modeling study, we show that the pandemic may be readily controllable through a combination of testing, treatment if necessary, and self-isolation after testing positive (TTI) of symptomatic individuals together with social protection (e.g., facemask use, handwashing).

We used an SEIR-type model incorporating asymptomatic but infectious individuals (40%) [1-3] to investigate how individual protective behaviors, different levels of testing, and isolation influence the transmission and control of the COVID-19 pandemic (Appendix). When the basic reproduction number, R_0, is 2.4 [12], 65% effective social protection alone (35% of the unprotected transmission) brings the R below 1 (Appendix). Alternatively, 20% effective social protection brings the reproduction number below 1.0 so long as 75% of the symptomatic population is covered by TTI within 12 hours of symptom onset (Figure A and Appendix). Even with 20% effective social protection, TTI of 1 in 4 symptomatic individuals can substantially "flatten the curve", cutting the peak daily incidence in half (Figure B, Appendix).

A


No social protection
20% effectiveness of social protection
40% effectiveness of social protection
50% effectiveness of social protection
60% effectiveness of social protection
Total number of infections (%)
Symptomatic individuals who are tested and isolated (%)
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100

B

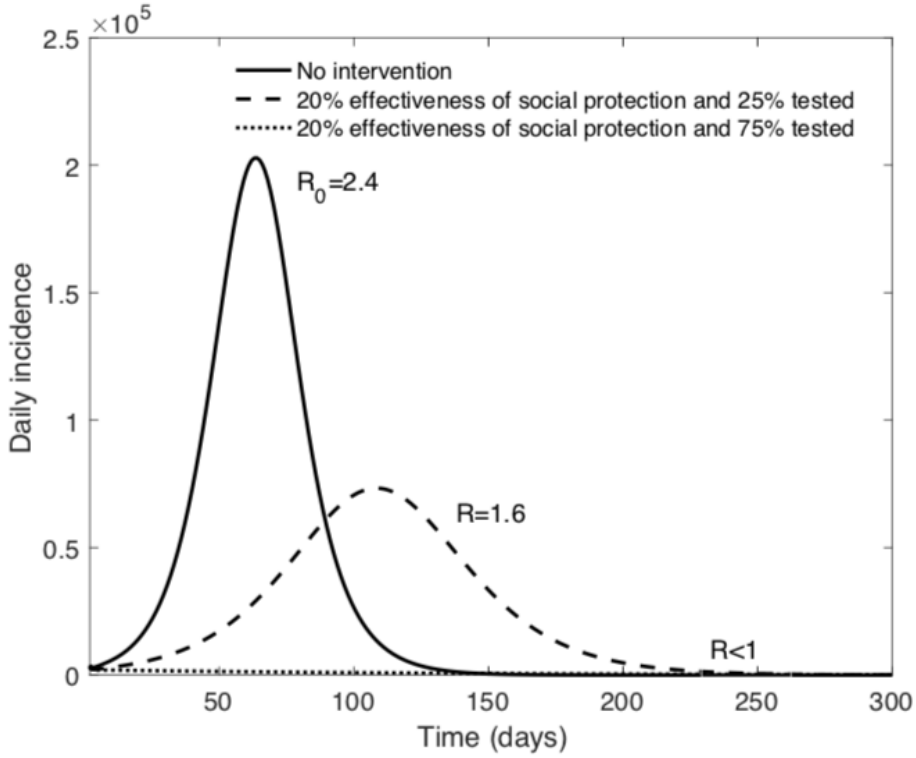

×10^5
No intervention
20% effectiveness of social protection and 25% tested
20% effectiveness of social protection and 75% tested
R0=2.4
R=1.6
R<1
Daily incidence
Time (days)
0
0.5
1
1.5
2
2.5
50
100
150
200
250
300

Figure. (A) Total number of infections in a population of 10 million individuals for varying levels of social protection and testing (TTI) at 12 hours testing delay and assuming 40% asymptomatic transmission. (B) Daily incidence in a population of 10 million individuals for 20% effectiveness of social protection and varying levels of testing (TTI) at 12 hours testing delay and assuming 40% asymptomatic transmission. Initial conditions were set as follows, susceptible individuals: 9,943,400; symptomatic individuals who underwent testing: 40,000; asymptomatic individuals: 16,000; and deceased individuals: 600.

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Supplementary Appendix to

Sustainable social distancing through facemask use and testing during the Covid-19 pandemic

Basic reproduction number, R_0

The basic reproduction number, R_0, is defined as the average number of secondary cases generated by primary infectious individuals during the early transmission phase in a completely susceptible population and in the absence of control interventions. This is a key metric to gauge the intensity and type of interventions that need to be implemented in order to bring the epidemic under control. For the ongoing epidemic of 2019-nCov, R_0 has been estimated at 2.4 (3.9, upper bound of 95% confidence interval).

Reproduction number with testing, isolation, and social protection

The reproductive number, R, quantifies the potential for infectious disease transmission in the context of a partially susceptible population. When R > 1, infection may spread in the population, and the rate of spread is higher with increasingly high values of R. If R < 1, infection cannot be sustained and is unable to generate an epidemic. As there are seven classes contributing to new infections, the reproduction number is the sum of the contributions of the infectious classes:

The contributions of the individual compartments are as follows

$$R = R^{E_2} + R^{A_n} + R^{A_s} + R^{J_a} + R^{I_n} + R^{I_s} + R^{J}$$

$$R^{E_2} = \beta \frac{q_e}{\kappa_2}$$

$$R^{A_n} = \beta \frac{\rho_a (1 - n_s) q_a q}{\gamma_1}$$

$$R^{A_s} = \beta \frac{\rho_a n_s q_a}{\alpha}$$

$$R^{J_a} = \beta \frac{\rho_a n_s h_a q_a}{\gamma_2}$$

$$R^{I_n} = \beta \frac{(1-\rho_a)(1-\rho_s)q}{\gamma_1}$$

$$R^{I_s} = \beta \frac{(1-\rho_a)\rho_s q}{\alpha}$$

$$R^{J} = \beta \frac{(1-\rho_a)\rho_s h}{\gamma_2}$$

Modeling the effect of testing, isolation and social protection of infected individuals

We employed an SEIR-type transmission model for modeling the transmission of COVID-19. Individuals within the model are classified as susceptible (S), latent (E_1), partially infectious but not yet symptomatic (E_2), asymptomatic and will not be tested (A_n), asymptomatic and will be tested and will be isolated (A_s), infectious and will not be tested (I_n), infectious and will be tested and isolated (I_s), hospitalized/isolated infectious (J), isolated asymptomatic (J_a), recovered (R), and deceased (D). Constant population size is assumed, so *N* is equal to the sum of individuals in all of the compartments. Further, seven classes can contribute to new infections: E_2, A_n, A_s, I_n, I_s, J, J_a. Susceptible individuals move to E_1 at rate $\beta[q_e E_2(t) + q_a q A_n(t) + q_a A_s(t) + qI_n(t) + qI_s(t) + h_a J_a(t) + hJ(t)]/N$, where β denotes the overall transmission rate. The transmission rate, β, was calibrated based on the baseline value of the basic reproductive number, $R_0 = 2.4$, which had been calculated.

Individuals in E_1 progress to E_2 at rate κ_1. Individuals from E_2 are partially infectious, with relative transmissibility q_e, and progress at rate κ_2, where a proportion ρ_a become asymptomatic and partially infectious (relative transmissibility q_a), and $1 - \rho_a$ become fully infectious. Among the proportion ρ_a who become asymptomatic, n_s will be tested, while 1- n_s will be undetected. Further, among the proportion $1 - \rho_a$ that become fully infectious, ρ_s will be tested, while $1 - \rho_s$ will be undetected. Asymptomatic individuals who are not tested and symptomatic individuals wear personal protective equipment (PPE) (such as wearing masks in public, handwashing, etc) and thus have relative transmissibility q, which is proportional to the level of effectives of PPE. Individuals within A_n and I_n classes (who are not tested) recover at rate γ_1. Those who are tested (I_s and A_s) will progress to the hospitalized and isolated class at diagnosis rate α, where relative transmission within hospitals and isolated places, h, can occur. However, we assume perfection isolation in our analyses. Individuals who are hospitalized and isolated progress to the recovered class at rate γ_2 or to the deceased class at rate δ.

Therefore, the system is defined by the following system of non-linear differential equations:

$$\dot{S}(t) = -\beta[q_e E_2(t) + q_a q A_n(t) + q_a A_s(t) + qI_n(t) + qI_s(t) + h_a J_a(t) + hJ(t)]/N$$
$$\dot{E}_1(t) = \beta[q_e E_2(t) + q_a q A_n(t) + q_a A_s(t) + qI_n(t) + qI_s(t) + h_a J_a(t) + hJ(t)]/N - \kappa_1 E_1(t)$$
$$\dot{E}_2(t) = \kappa_1 E_1(t) - \kappa_2 E_2(t)$$
$$\dot{A}_n(t) = \kappa_2 \rho_a (1 - n_s) E_2(t) - \gamma_1 A_n(t)$$
$$\dot{A}_s(t) = \kappa_2 \rho_a n_s E_2(t) - \alpha A_s(t)$$
$$\dot{J}_a(t) = \alpha A_s(t) - \gamma_2 J_a(t)$$
$$\dot{I_n}(t) = \kappa_2 (1 - \rho_a)(1 - \rho_s) E_2(t) - \gamma_1 I_n(t)$$
$$\dot{I}_s(t) = \kappa_2 (1 - \rho_a) \rho_s E_2(t) - \alpha I_s(t)$$
$$\dot{J}(t) = \alpha I_s(t) - \gamma_2 J(t) - \delta J(t)$$
$$\dot{R}(t) = \gamma_1 (A_n(t) + I_n(t)) + \gamma_2 (J(t) + J_a(t))$$
$$\dot{D}(t) = \delta J(t)$$

Schematic of the model diagram

The population is classified into 10 epidemiological states: susceptible (S), latent (E_1), partially infectious but not yet symptomatic (E_2), asymptomatic and will not be tested (A_n), asymptomatic and will be tested and will be isolated (A_s), infectious and will not be tested (I_n), infectious and will be tested and isolated (I_s), hospitalized/isolated infectious (J), isolated asymptomatic (J_a), recovered (R), and deceased (D). Model parameters are described in Table 1.

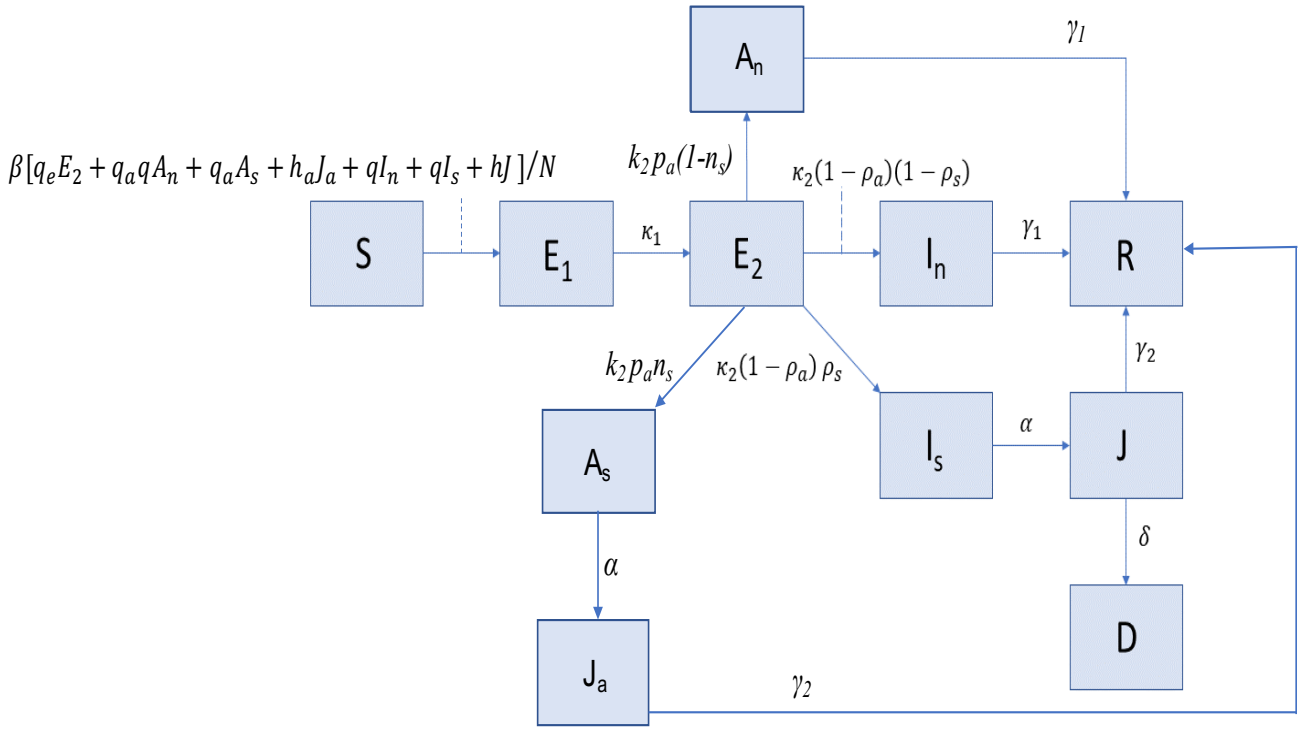
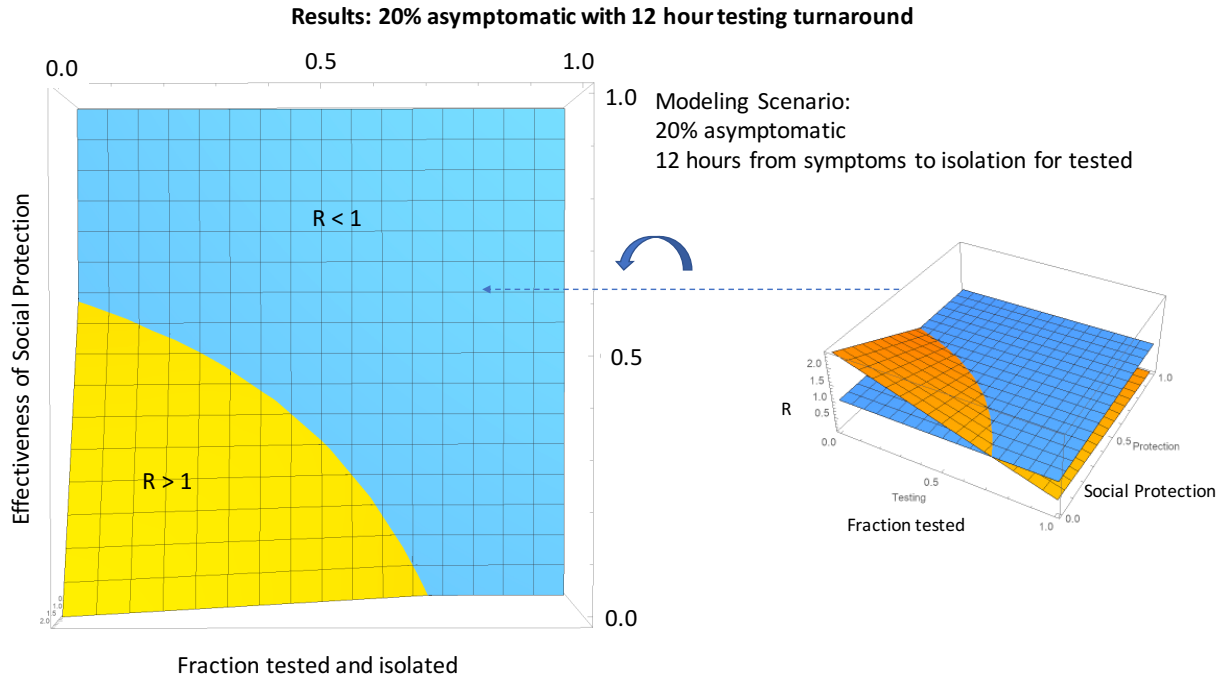


Table 1. Parameter descriptions and values for model (Indicates the value was estimated)**

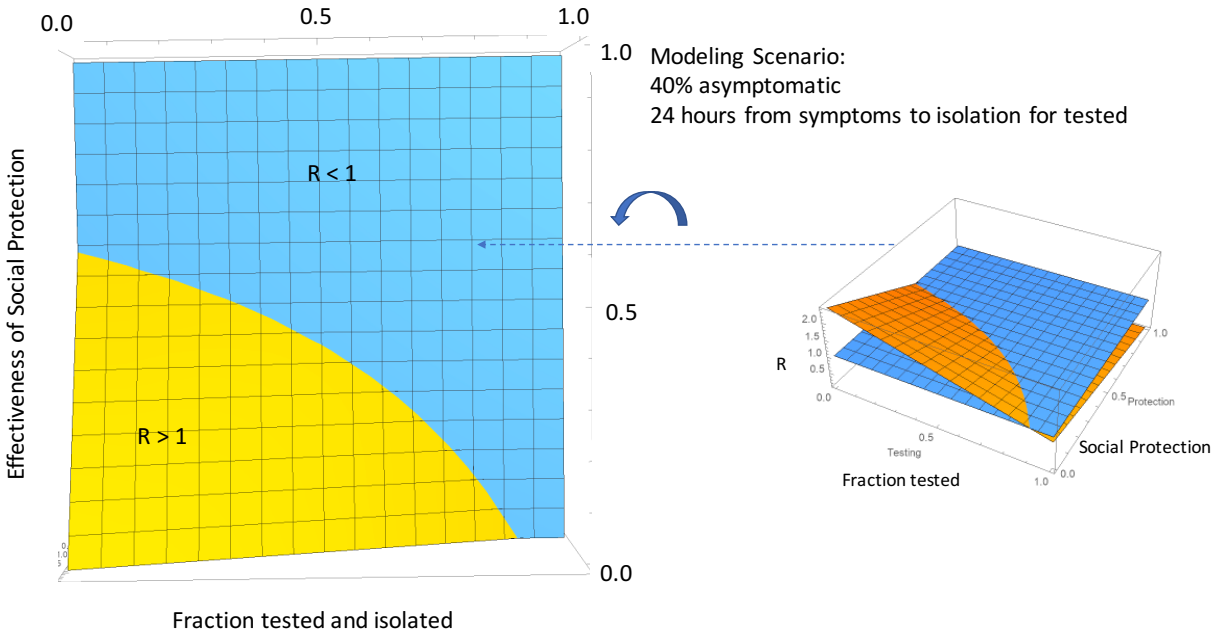
Parameter	Description	value	Refs.
B	Transmission rate	Calibrated for R_0=2.2 or R_0=3.9	**
H	Relative isolation transmissibility of infected individuals	0	Assumed here
h_a	Relative isolation transmissibility of asymptomatic individuals	0	Assumed here
q_e	Relative transmissibility of exposed individuals	0.1	[1]
q_a	Relative transmissibility of asymptomatic cases	0.4	[1]

Q	Level of effectiveness of personal protective equipment (PPE) such as mask and wand washing	0-100%	
$1/\kappa_1$	Length of latent period	2.5 days	[2-6]
$1/\kappa_2$	Length of infectiousness prior to symptom onset	2.5 days	[4-7]
ρ_a	Proportion of exposed individuals who become asymptomatically infected	20%, 40%, and 60%	[8, 9]
n_s	Proportion of asymptomatic individuals who will be tested and isolated	0%	Assumed here
ρ_s	Proportion of fully infectious individuals that undergo testing	0-100%	
$1/\alpha$	Time from symptom onset to isolation or hospitalization	1, 2 days, and 12 hours	
$1/\gamma_1$	Time from illness onset to recovery	7 days	[2, 3]
$1/\gamma_2$	Length of time from diagnosis to recovery	5 days	[10]
Δ	Death rate within hospitals	$\delta = 0.04$	[11]

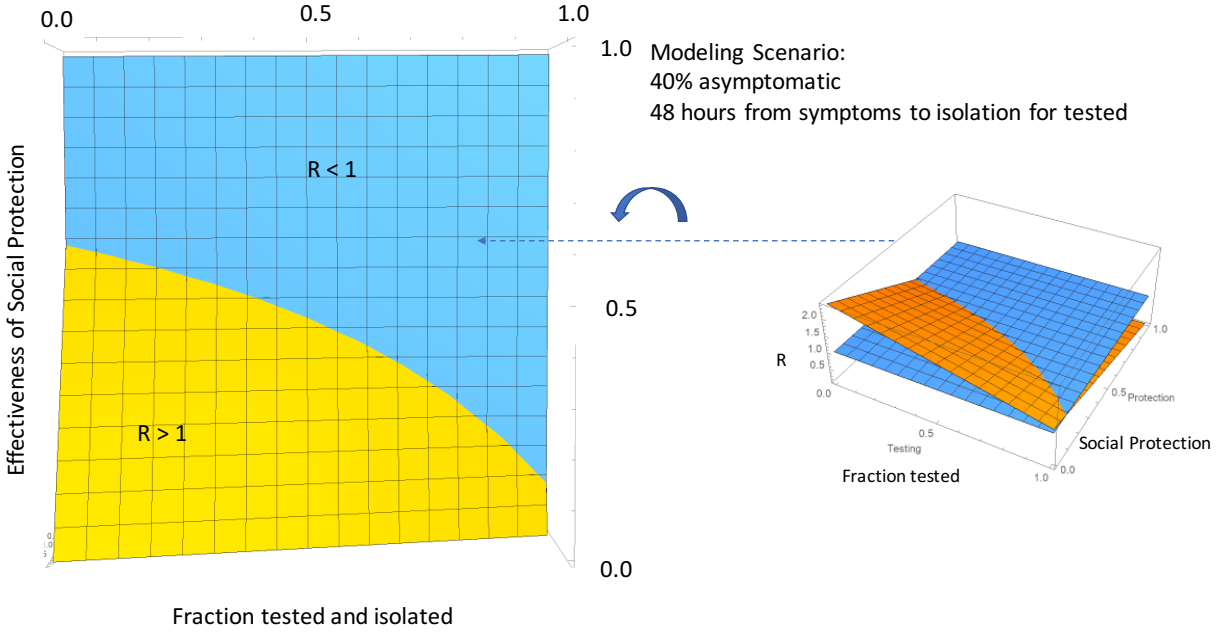
Figure 1. Thresholds for social protection and testing / isolation needed to bring R < 1.



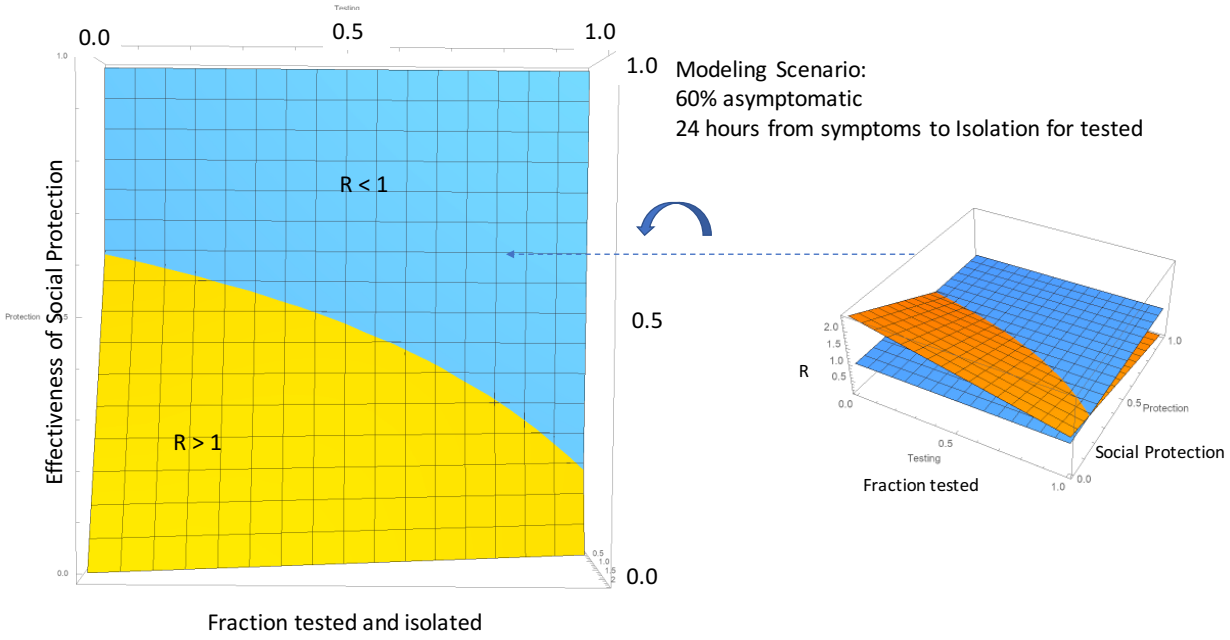
Results: 40% asymptomatic with next day testing turnaround



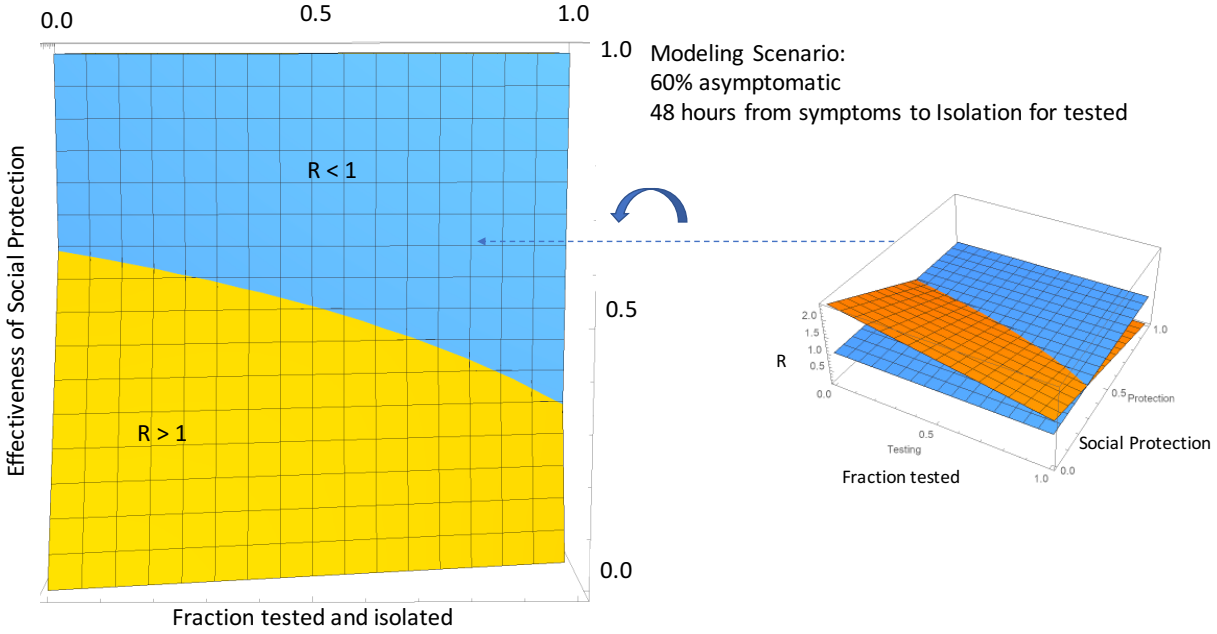
Results: 40% asymptomatic with two-day testing turnaround



Results: 60% asymptomatic with one-day testing turnaround



Results: 60% asymptomatic with two-day testing turnaround



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