Minimizing Economic Costs for COVID-19

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It is often claimed that there is a trade-off between containing COVID-19 and minimizing disruption to the economy, and that eliminating COVID-19 (by which we mean getting to no community transmission—i.e. no cases from unknown sources) is too costly to be worthwhile. Here, we examine the validity of these claims.

We consider a space of policy action in which a country (or state) decreases its number of cases per day by reducing the reproductive number R below 1 for a duration of its choosing and then maintains thereafter a constant number of cases per day. The question is what is the right level at which to maintain this constant number of cases per day. The essential idea is that there are two strategies: 1) an *elimination strategy* in which $R < 1$ is maintained until there is no more community transmission and after which the country reopens (save for targeted responses in specific locations to combat cases that are imported), and 2) a *steady-state strategy*, in which $R < 1$ is maintained for some period of time but not long enough to eliminate community transmission and after which $R = 1$ is maintained nationwide.

The elimination strategy requires a greater upfront cost, since $R < 1$ is maintained for a longer duration, but requires lower costs thereafter since economic activity in the country can largely return to normal, with the exception of targeted measures in specific locations in the event of a second outbreak caused by an imported case. The steady-state strategy, on the other hand, requires the costly maintenance of $R = 1$ nationwide in order for cases not to rise; if community transmission is not eliminated and $R = 1$ is not maintained, a second wave will occur sooner or later, as has already occurred in many countries that have not yet chosen the elimination strategy. Because of the long time during which a country must maintain $R = 1$ under the steady-state strategy, it is worthwhile even from a purely economic perspective for a country in almost all cases to instead choose the elimination strategy, despite its greater short-term costs.

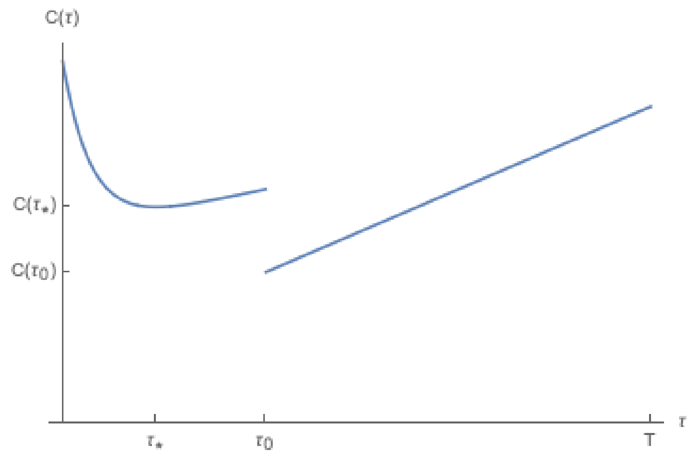

FIG. 1. The total cost $C(\tau)$ over a time horizon T of maintaining $R < 1$ (corresponding to an exponential rate of decrease r) for a duration of τ and then maintaining a constant number of cases for a duration $T - \tau$. The minimum cost occurs at $\tau = \tau_0 = \frac{\ln n_0}{r}$, which corresponds to the elimination of community transmission and thus the ability to use less costly measures to contain the virus. (The increase in cost for $\tau > \tau_0$ occurs since there is a cost but no benefit to maintain $R < 1$ after community transmission has been eliminated.) However, a local but not global minimum occurs at τ_*, for which the number of cases per day is reduced to a relatively low level but for which community transmission is allowed to persist, thereby necessitating that $R = 1$ be maintained nationwide thereafter.

ECONOMIC MODEL

We consider a model in which a country starts with a case rate (cases per day) of n_0. The country then chooses an amount of time τ during which it decreases its number of new cases per day at a rate r. There is an economic cost to decreasing these cases at a rate r of $c_1(r)$, and there is also a cost per case of c_2, which includes healthcare costs, lost economic productivity, the human cost, etc.

The number of new cases per day is thus given by $n_0 e^{-rt}$ for $t \leq \tau$. After time τ, the country maintains a constant number of cases per day $n = n_0 e^{-r\tau}$ for a duration of $T - \tau$ where T is the time horizon of the model. A small enough number of cases per day in the continuous model corresponds to the elimination of community transmission in reality. Thus we assume a threshold, which we take to be 1 case per day, such that $n \leq 1$ corresponds to the elimination strategy, for which there is a cost A of containing importations and any residual cases. Above this threshold ($n > 1$), the cost of maintaining a constant number of cases requires $R = 1$ nationwide and so is taken to be $c_1(0) + c_2 n$. We thus define

$$c_0(n) = \begin{cases} c_1(0) + c_2 n & n > 1 \\ A & n \leq 1 \end{cases} \tag{1}$$

and note that A will be significantly less than the cost $c_1(0)$ of maintaining $R = 1$ nationwide.

We can then consider the total cost $C(\tau)$ of a course of action as

$$C(\tau) = \int_0^\tau \left(c_1(r) + c_2 n_0 e^{-rt}\right) dt + (T-\tau) c_0(n) \quad (2)$$

where $n = n_0 e^{-r\tau}$.

The time τ to achieve $n \leq 1$ is $\tau_0 \equiv \frac{\ln n_0}{r}$. For $\tau < \tau_0$,

$$\begin{aligned} C(\tau) - C(\tau_0) > \\ \tau c_1(r) + (T-\tau)c_1(0) - \tau_0 c_1(r) - (T-\tau_0)A \\ \geq T(c_1(0) - A) - \tau_0(c_1(r) - A) \end{aligned} \quad (3)$$

Thus, if $\tau_0(c_1(r) - A) < T(c_1(0) - A)$, an inequality that will hold when the time horizon T (on the order of at least several months if not years—see discussion of time horizons below) is substantially larger than the time to elimination τ_0 (usually on the order of weeks), then the elimination strategy will be less costly, often significantly so. Note that this inequality does not include c_2 and therefore does not take into account the fact that the elimination strategy results in fewer people getting sick but rather deals in the costs (economic and otherwise) of social distancing measures alone.

Figures 1 and 2 give a qualitative picture of the costs of the two strategies: the elimination strategy, in which $\tau = \tau_0$, and the steady-state strategy, in which $\tau < \tau_0$. For the steady-state strategy, there may be a duration τ_* that minimizes the costs for $\tau < \tau_0$ but that still results in higher costs than the elimination strategy (i.e. $C(\tau_*) > C(\tau_0)$). It is a common trap for a country to hold measures in place only for a duration of approximately τ_*. At this local minimum τ_*, countries engaging in short-term thinking may at this point start to lift the social distancing measures, since after a duration τ_* it is worth extending the measures that keep $R < 1$ only if they are held in place until the elimination of community transmission. If they are held in place until elimination, the country can open back up, but otherwise the country must either maintain (whether by the voluntary action of its citizens or government action) $R \sim 1$ or else, sooner or later, a second wave will occur.

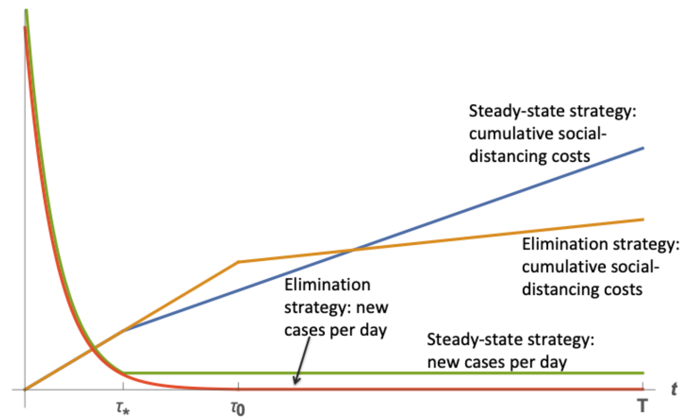

FIG. 2. The cumulative costs (economic and otherwise) from social distancing (not including the economic and human costs of the cases themselves) as a function of time t for the two different strategies are shown, together with the number of new cases per day for the two strategies. In the elimination strategy, measures are put in place that cause the number of cases to decline until all community transmission is eliminated, while in the steady-state strategy, the measures are held in place only until the number of cases is at a sufficiently low (42 cases per day for the parameters used to create this figure, from an initial 1000 cases per day), after which a steady-state is maintained. We see that even when not considering the costs (economic and human) of people getting sick and sometimes dying, it is preferable to endure the short-term extra costs between τ_* and τ_0 (see fig. 1 or the text for a definition of these times) in order to greatly reduce the total accumulated costs in the longer term.

ADDITIONAL CONSIDERATIONS

Further reducing costs with green zones. In this analysis, the elimination strategy assumes that $R < 1$ must be maintained until there is no community transmission anywhere in the country. But with internal travel restrictions, a "green zone" approach can be used in which regions within the country can open up one by one as community transmission is eliminated within each region, with travel allowed between two regions once both regions have eliminated community transmission [1]. Furthermore, the fact that transmission occurs predominantly locally means that the time until community transmission will be eliminated in a region i will be closer to $\frac{\ln n_0^i}{r}$ (rather than $\frac{\ln n_0}{r}$), where $n_0^i << n_0$ is the number of initial cases per day in region i (rather than in the country as a whole). Finally, as the number of new cases per day decreases, contact tracing becomes more effective, which can further hasten the elimination of community transmission. Thus, the time to elimination τ_0 may be significantly shorter than $\frac{\ln n_0}{r}$, resulting in a substantially lower cost of the elimination strategy.

Time horizon and vaccines. The time horizon T is unknown. If there is an effective vaccine that gives long-lasting immunity, T will be the time until that vaccine is deployed. However, there is no such guarantee, and in the absence of such an effective vaccine, T could be far longer. Even for a relatively short $T = 200$ days (the number used for figs. 1 and 2), realistic parameter estimates indicate that the elimination strategy is significantly less costly than the steady-state strategy. In particular, $c_1(r) - c_1(0)$ is going to be less than $c_1(0) - A$ (unless r is chosen to be unrealistically high) since the cost of A corresponds to a society largely back to normal, while both $c_1(r)$ and $c_1(0)$ involve a significant reduction in both economic and social activity. Thus, we expect $c_1(r) - A < 2(c_1(0) - A)$ and so as long as elimination can be achieved in less than 100 days, the elimination strategy will be preferred even when the fact that fewer people overall will get sick and die is not taken into account (eq. (3)). The possibility of there being no end in sight for COVID-19 makes the difference in expected cost between the elimination and steady-state strategies far larger.

Containing importations. Included in the cost A is the possibility that an imported case will lead to another uncontained outbreak that may require a local lockdown in a small part of the country [2]. These infrequent local lockdowns, if enacted shortly after an outbreak becomes uncontained, will be short in duration such that at any one time all or almost all of the country is opened up. Thus, even with these potential local lockdowns, the cost A is far less than the cost $c_1(0)$ of maintaining $R = 1$ throughout the entire nation.

Strength of social distancing measures. In reality, the rate of exponential decrease r that occurs for $R < 1$ is not fixed but depends on the extent of the social distancing measures imposed. (For $R < 1$, r is related to R by $1 = \int_0^\infty Rg(t)e^{rt}dt$ where $g(t)$ is the distribution of generation intervals [3].) Choosing a larger r (i.e. faster decrease in cases) is more costly but results in a faster elimination of community transmission. For the elimination strategy, the optimal r is given by minimizing

$$C(\tau_0) = \frac{c_2(n_0 - 1)}{r} + \frac{\ln n_0}{r}(c_1(r) - A) + TA \qquad (4)$$

with respect to r, yielding $rc_1'(r) = c_1(r) - A + \frac{c_2(n_0-1)}{\ln n_0}$. Defining $\tilde{c}_1(r) = c_1(r) - A + \frac{c_2(n_0-1)}{\ln n_0}$ yields

$$\frac{d \ln \tilde{c}_1(r)}{d \ln r} = 1 \qquad (5)$$

Thus, we see that the strength of social distancing measures should be increased as long as the resulting percentage increase in r is greater than the resulting percentage increase in the effective cost $\tilde{c}_1(r)$.

It is important to distinguish between two types of measures that increase r (the rate of decrease in new cases per day). One type has an economic cost proportional to the entire population and involves general social distancing, shutting down non-essential services, etc. The other type has an economic cost proportional to the number of cases and involves isolating infected individuals in hotels, contact tracing, etc. Given a certain level of population-wide measures, it is important to also implement the measures that are proportional to the number of cases since, given the small fraction of individuals who will be infected at any one time, the percentage increase in costs will be small relative to the percentage increase in r.

[1] EndCoronavirus. Green zones. endcoronavirus.org/green-zones, 2020. Accessed 2020-8-5.

[2] Alexander F Siegenfeld and Yaneer Bar-Yam. Eliminating COVID-19: The impact of travel and timing. *arXiv:2003.10086*, 2020.

[3] Jacco Wallinga and Marc Lipsitch. How generation intervals shape the relationship between growth rates and reproductive numbers. *Proceedings of the Royal Society B: Biological Sciences*, 274(1609):599–604, 2007.