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Commentary

Biology, behavior and policy, or, Dr. Fauci, Sen. Paul and Prof. Lucas walk into a pandemic

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In a highly-publicized recent exchange in the U.S. Senate, Dr. Anthony Fauci and Sen. Rand Paul expressed radically different views on the level of herd immunity needed to contain the coronavirus epidemic. Sen. Paul noted that transmission rates in New York City appeared low, despite the virus's high inherent infectiousness, proposing that this was evidence that the share of the population already infected was sufficient to have reached herd immunity. Dr. Fauci memorably responded, "If you believe 22% is herd immunity, I believe you're alone in that" [1].

For Sen. Paul, the implication of a low threshold for herd immunity is that restrictions on activity can be reduced without risking runaway disease transmission. If correct, this would be welcome, since such restrictions have immense economic, health and emotional costs. Unfortunately, his policy recommendation suffers from a crucial flaw in logic: it ignores the Lucas critique.

Prof. Robert Lucas's Nobel-prize-winning insight, developed in the study of the unemployment-inflation tradeoff in macroeconomics, was that empirical relationships observed under one policy regime cannot necessarily be used to argue for a change in policy [2]. The logic is simple, but profound: the relationships we observe in the data depend on behavior, and behavior responds to and is affected by policy, so when policy changes we should expect behavior to change as well. As a result, we cannot expect the empirical relationships observed under the previous policy regime to continue under the new policy regime, nor can we claim that our new policy will have the effects we would anticipate if behavior were fixed.

How does this insight from macroeconomics apply to coronavirus and herd immunity? Suppose we grant Sen. Paul's claim that, in previously hard-hit areas such as New York City, relatively low shares of the population previously infected have contributed in important ways to slowing the spread of disease. Even so, his policy conclusion—that distancing, masking and restrictions on activity can safely end—does not follow. The Lucas Critique reminds us that by changing policy, we change behavior, which in turn will affect the relationships on which we based our policy change.

A little math can help. In a standard, simple epidemiological model, the population threshold for herd immunity, commonly denoted p, is given by the formula

$$p = 1 - (1/R0),$$

where R0 is the basic reproduction number and refers to the expected number of secondary cases that result from one infected case.

For an extremely contagious disease like measles, R0 might be about 10, leading to a p of about 0.9, which is why attaining high rates of immunization is so important. For a much less contagious disease, the threshold is lower. For example, if R0 = 1.2, then $p = 0.17$. Once more than 17% of the population is immune, whether through infection or from vaccination, we expect the disease to die out. The details change in more complex models, for example if different subpopulations spread the disease at different rates, or if acquired immunity is only partial, but the basic insight is the same: the less infectious a disease is, the lower the herd immunity threshold.

While this insight is correct, it is easy to make two conceptual mistakes. The first mistake would be to assume that R0 is a fixed, intrinsic biological property of a disease. While some diseases are inherently more contagious than others, R0 is a result of both biology (i.e., duration of being contagious, risk of infection for a given level of exposure) but also of environment and behavior (i.e., contact rate between susceptible and infected individuals, amount of exposure when a contact occurs) [3]. This is why we should wear masks, maintain physical distance, meet other people outdoors rather than indoors whenever feasible, and so on: even if we cannot change the inherent infectiousness of the disease, we can still reduce R0.

The second mistake would be to forget the Lucas critique: even if we concede that the low share of previously infected people exceeded a herd immunity threshold, it does not follow that we can use this observation to argue for fewer restrictions on activity, or to tell the public that fewer precautions are needed. If indeed the herd immunity threshold was low, it is likely that this was in large part

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because public policy and private behavior contributed to keeping R0 low. Policies such as shelter-in-place orders have successfully reduced mobility and COVID-19 transmission across the US [4]. If we were to change policy or encourage less cautious private behavior, R0 would likely increase, and the herd immunity threshold would increase as well.

Why does this matter for the future? Going forward, understanding how interactions among biology, behavior and policy affect outcomes will continue to be crucial for good policy design, while neglecting to consider how behavior may change in response to new interventions and policies may undermine progress. For example, recent weeks have brought positive news on vaccine development, including the approval and initial distribution of vaccines in several countries. In addition to saving many lives, the arrival of these vaccines will allow less restrictive policies, and vaccinated individuals will naturally and rationally increase their levels of activity as vaccination reduces risks to their health. On balance, this increase in activity will be welcome and beneficial. However, it will likely dampen some of the benefits of the vaccine, because increased activity will push R0 back up among those who are unlucky enough not to be protected by the vaccine. Since we will not know in advance who will have this bad luck, policy should continue to encourage low-cost mitigation, such as masking, ventilation of indoor spaces, and modest physical distancing, and policymakers should be cautious about lifting restrictions on large gatherings, especially indoors.

On an even more basic level, the change in behavior could even undermine the level of protection the vaccine provides. In the double-blind placebo-controlled field trials of these vaccines, vaccine recipients still had a strong incentive to protect themselves and limit their own exposure, for two reasons. First, they did not know whether they had received the vaccine rather than the placebo. Second, at the time, it was not yet known that the vaccine would be effective. In contrast, an individual who knows she has received an approved, effective vaccine may reasonably and rationally take fewer precautions. The result is that early individuals to receive a vaccine may actually face higher levels of viral exposure than the experimental population did, since their behavior may change while, at least at early stages of vaccination, the overall level of infection in the community has not yet been reduced. We do not know how the vaccine will perform in this new context, and the growing evidence that higher intensity of exposure is associated with more severe illness should make us cautious [5]. Again, public communication and policy should continue to encourage basic, low-cost protections to the extent possible, and will need to balance encouraging vaccine takeup with reminders not to abandon basic precautions. In particular, we suggest it will be useful to emphasize the "layers" mental model: [6] vaccines add an additional layer of protection. This additional layer may allow us to remove some existing layers that are especially burdensome, but should not lead us to remove all other layers, especially those which are low cost.

This caution is especially necessary in these early stages because it is not yet clear that these vaccines provide *sterilizing* immunity. That is, even though the results of major trials have shown that the vaccines reduce illness, it is not known whether, or to what extent, they prevent infection and ongoing transmission [7]. Some data suggest a reduction in infection from at least one of the vaccines [8], which is positive news, but these are preliminary results and need further data and study before we can be confident. If the vaccine does not provide significant sterilizing immunity, then individuals or subgroups who a vaccine does not protect, or who choose not to be vaccinated, will still be at serious risk. In fact, the risk to these groups may be even greater than it is without a vaccine, since the less cautious behavior of others may accelerate transmission [9]. That is, to the extent that a vaccine prevents infection and onward transmission, it produces a positive externality: by vaccinating yourself, you make others safer. However, to the extent that it induces less cautious behavior, it may create a negative externality. On balance, of course, vaccines are overwhelmingly beneficial, but we can guard against the possibility of this negative unintended consequence by maintaining basic protections.

This question of whether, and to what extent, these vaccines provide immunity – as opposed to just protection – is vitally important. Careful monitoring of those who have been vaccinated in trials, as well as a sample of those who receive early vaccines, is urgently needed to provide data on this crucial question. In addition to continuing to collect infection rates among trial participants [8], data on non-participating members of their households can inform the question of whether vaccination prevents transmission within households [10].

While it is reasonable to lift the highest-cost restrictions, such as school closures, before this question is resolved, policy and communication should continue to encourage low-cost protections like mask-wearing, and medium-cost interventions like improved ventilation and air filtration, especially in schools. This cautious approach will likely delay the safe return of valued services like indoor dining. Compensating affected workers and business owners will soften the economic impact of this caution and may reduce political resistance.

Declaration of Interests

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