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Who Should Get Vaccines First?

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We study optimal vaccination policies using a novel theoretical framework. We characterize the optimal vaccine allocation scheme in our model, which entails giving the highest priority to people with intermediate vulnerability and giving greater weight to potential exposure rather than vulnerability. Numerical results demonstrate that this approach performs significantly better than commonly considered strategies, in particular prioritizing only people who are the most vulnerable to severe illness.

Vaccination policies are crucial to eradicating pandemics. Given the scarcity of supply and the urgent need for rollout, optimizing vaccine allocation is of paramount importance. Prevailing views revolve around two key considerations: vulnerability risk and transmission risk.

Sensible arguments can be made for allocating the vaccine to those most likely to suffer severe symptoms, as well as to those most likely to contract and spread the disease. Thus far, however, policymakers and researchers have devoted little attention to the role that incentives and behavior play in designing optimal vaccine policy.[1]

A recent report by the World Health Organization documents the growing importance and policy relevance of various behavioral incentives under the heading "lockdown fatigue," referring to the rejection of mandatory isolation requirements.[2] Prudent policy design should account for human behavior rather than establishing rules under the assumption of full compliance.

A burgeoning literature aims to incorporate behavior into standard susceptible-infected-recovered (SIR) dynamic epidemiological models, primarily to study the evolution of contagion rates.[3] These and other similarly quantitative models offer a strong methodology for generating robust predictions.

However, they quickly become analytically unwieldy when combined with other considerations, such as individuals who vary across multiple dimensions. These models can be used to compare particular policies but are not well-suited to characterizing the optimal vaccine prioritization scheme in complex settings.[4] This complexity is necessary to ascertain the relative importance of vulnerability risk versus transmission risk in vaccine prioritization policies.

Vulnerability and Transmission Risk

That's why we take a different, complementary approach in a recent working paper.[5] We develop a simple, tractable model that abstracts from the dynamic considerations found in SIR models but allows for a rich level of vulnerability risk and transmission risk heterogeneity across individuals, as well as behavior that responds to the state of the pandemic. Throughout the analysis, an individual's overall risk of severe disease is a product of vulnerability and exposure.

Vulnerability refers to a person's likelihood of experiencing severe symptoms or death if infected, which, in the model, is due solely to factors beyond the individual's control within the timeframe of the pandemic. In the real world, vulnerability is likely a function of age or underlying health conditions.

Exposure refers to the frequency of interactions with others, during which an individual can contract or spread the disease. Unlike vulnerability, exposure is a function of behavior as well as factors beyond the individual's control. This assumption captures the idea that some people have jobs, social circles or living conditions that involve more frequent contact with others, but that they can take costly actions — such as working from home or changing their living circumstances — to avoid those interactions.

We characterize the optimal allocation of vaccines and provide useful qualitative insights to guide real-world vaccination policy. The baseline analysis produces two main findings:

- First, among individuals with the same level of overall risk, it is better to vaccinate those whose risk is due to a high level of exposure rather than a high level of vulnerability.
- Second, if optimal lockdown policies are not implemented or followed, it is best to give special priority to individuals who tend to interact more than is socially optimal.

The model also provides insight into when it is better to vaccinate with the goal of herd immunity rather than directly protecting particular individuals.

A Tractable Model of a Pandemic

We develop a model with a large number of individuals indexed by both their probability of potential exposure to others (entering and expanding the interaction pool) and their probability of suffering severe reactions to the disease if they become infected. A person's overall risk of a severe reaction is the product of the two probabilities multiplied by a term common to all people that reflects the aggregate state of the pandemic.

The larger the number of individuals in the interaction pool, the higher the probability of contracting the disease in the pool. As a consequence, holding vulnerability fixed, an individual with a higher exposure not only faces a higher risk of an adverse outcome but also exerts a greater negative externality on others by increasing the size of the interaction pool.

Finally, an individual may self-isolate by paying a cost to avoid interactions. We impose that the cost of self-isolation is higher for people with a greater probability of potential exposure. It follows that, holding vulnerability fixed, people with a higher exposure face a greater burden from the pandemic because they must choose between a greater risk of infection and a higher cost of self-isolation. This assumption captures the notion that those who tend to interact more during normal times also face a higher cost of avoiding others during the pandemic.

We take as given a fixed quantity of vaccines that yield full protection from infection and asymptomatic spread, and ask: How should a policymaker allocate vaccines based on individuals' exposure risk and vulnerability risk to minimize the total costs of infection and self-isolation? In the primary extension of the model, we also allow the policymaker to choose which individuals will isolate, which we refer to as a mandatory lockdown policy.

Results

Our baseline analysis displays three striking features. First, people with intermediate vulnerability are vaccinated more than those who are either more or less vulnerable. Such individuals interact more than is socially optimal, so they are particularly costly to society when unvaccinated. Indeed, it is always optimal to first vaccinate these people when supplies are limited.

Second, among those not self-isolating, the optimal policy exhibits an exposure premium: Vaccination is not based on overall risk. Instead, greater weight is given to exposure than vulnerability. More specifically, holding overall risk fixed, it is better to vaccinate those whose risk is due to a high level of exposure than due to a high level of vulnerability. This feature reflects the social value of vaccinating individuals who tend to infect others.

Third, among those in self-isolation, the policy depends only on exposure, not on vulnerability. Self-isolating individuals are vaccinated if their exposure, and thus their cost of self-isolation, is sufficiently high.

The latter two properties reveal two different ways that individuals' exposure is more relevant for vaccine allocation than their vulnerability. For those who self-isolate, their behavior eliminates the importance of differences in vulnerability, yet the cost of this behavior goes up along with their potential frequency of interaction. For those who do not self-isolate, exposure and vulnerability contribute equally to their private overall risk, but only their exposure contributes to the risk they impose on others.

We also characterize the optimal allocation of vaccines when the optimal mandatory lockdown policy is in place. This yields two insights into the distortions that private incentives concerning isolation entail. First, for those with either high or low vulnerability, social and private incentives agree on whether self-isolation is worth the cost. However, social incentives imply that those with intermediate vulnerability should isolate, while private incentives — which do not include the risk of infecting others — make self-isolation seem too costly.

Second, the value of taking into account spillovers when vaccinating — the driving force behind the exposure premium and giving priority to those with intermediate vulnerability — is low when the optimal mandatory lockdown policy is not implemented and there are many individuals who are indifferent or nearly indifferent between self-isolating and interacting. As high-interaction individuals are vaccinated and the risk of transmission falls, people who were self-isolating may decide it is now safe enough to interact. If these newly interacting individuals are not considering (or are not incentivized to consider) their effect on others, then this decrease in self-isolation is costly to society and undoes the initial decrease in infection rates.

Comparing Optimal and Simple Vaccination Strategies

In addition to these theoretical findings, we perform various numerical exercises in part to compare the optimal policy to commonly considered simple strategies, such as:

- Policies that vaccinate only the most vulnerable
- Policies that vaccinate only the most interactive
- Policies that vaccinate according to overall risk

A consistent finding is that policies that vaccinate only the most vulnerable perform significantly worse compared to other commonly considered strategies, as well as to the optimal policy. This performance gap is largest when vaccine supply is heavily constrained or the disease is particularly contagious or deadly. In those cases, such policies end up targeting only individuals in isolation and generate no spillovers.

This result is particularly significant because many countries implement such policies at the start of a vaccine rollout, precisely when supply is most limited. Importantly, in the optimal policy, some of the most vulnerable remain unvaccinated, but they still benefit from the

spillovers generated by focusing vaccinations on those who interact frequently.

Qualitative Guidelines for Vaccination Policy

Although our model abstracts from important quantitative considerations, it provides qualitative insights into the optimal vaccination prioritization scheme. First, people's overall risk is the product of their vulnerability and their frequency of interaction, but only the latter puts others at risk. Therefore, holding overall risk fixed, vaccinations should target those who are more likely to expose others. Second, self-isolation mitigates the importance of differences in vulnerability. Among those who avoid interaction, preference should be given to individuals whose self-isolation is more costly. Third, it is best to vaccinate people who tend to interact often and more than is socially optimal — while being careful not to incentivize further suboptimal interaction — because they impose large costs on others. Finally, to get the largest spillovers from vaccinating the most exposed people, policymakers should discourage increased interaction in response to falling infection rates.

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[1] *For a recent paper that studies optimal vaccination taking as given individual behavior and infection rates, see Ana Babus, Sanmay Das and SangMok Lee, "The Optimal Allocation of Covid-19 Vaccines," Covid Economics 44, Centre for Economic Policy Research, Aug. 25, 2020, pp. 47–71.*

[2] *See World Health Organization Regional Office for Europe, "Pandemic Fatigue: Reinvigorating the Public to Prevent COVID-19," revised in November 2020.*

[3] *For a comprehensive review, see Sebastian Funk, Marcel Salathé and Vincent A. A. Jansen, "Modelling the Influence of Human Behaviour on the Spread of Infectious Diseases: A Review," Journal of the Royal Society Interface, Sept. 6, 2010, vol. 7, no. 50, pp. 1247–1256.*

[4] *For a recent example focused on the HIV/AIDS epidemic in Malawi, see Jeremy Greenwood, Philipp Kircher, Cezar Santos and Michèle Tertilt, "An Equilibrium Model of the African HIV/AIDS Epidemic," Econometrica, July 2019, vol. 87, no. 4, pp. 1081–1113.*

[5] *Nikhil Vellodi and Joshua Weiss, "Optimal Vaccine Policies: Spillovers and Incentives," Federal Reserve Bank of Richmond Working Paper No. 21-06, March 2021.*

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