‘The Pandemic Is a Prisoner’s Dilemma Game’

Using game theory, researchers modeled two ways of prioritizing vaccinations, to see which saved more lives.

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Madhur Anand, an ecologist, right, and Chris Bauch, a mathematical biologist, focus their research on the interplay between human behavior and environment systems.Ian Willms for The New York Times

Madhur Anand, an ecologist, and her husband, Chris Bauch, a mathematical biologist, were optimally situated during the spring lockdown, working from home in Guelph, Ontario, to watch the pandemic play out — and to discuss patterns of behavior, within their community and beyond, as we all tried to keep safe and carry on.

Their offices at home are separated only by a wall, rather than a 45-minute drive. Dr. Anand is the director of the new Guelph Institute for Environmental Research at the University of Guelph, and Dr. Bauch runs a lab at the University of Waterloo. The couple's collaborative research usually focuses on the interplay between human behavior and environment systems — for instance, with pollution, deforestation and climate change. Whereas those dynamics unfold slowly, the pandemic provided an acute example of rapid change.

"Societal change is not the kind of thing you can easily experiment with," Dr. Anand said. "But here we were in the middle of a huge social experiment."

Like many scientists, they redirected their research to Covid-19. The resulting study, led by their doctoral student Peter Jentsch and currently under peer review, looked at vaccination prioritization: To save the most lives, who should get the vaccine first?

As infectious disease studies go, their methodology was somewhat atypical because it applied game theory, a mathematical way of modeling how people make strategic decisions within a group. Each individual has choices, but the payoff for each choice depends on choices made by others. This is what's called a "prisoner's dilemma game" — players weigh cooperation against betrayal, often producing a less than optimal outcome for the common good.

The pandemic presents an everyday complexity of such choices. Imagine, Dr. Bauch said, if everyone followed public health recommendations: They wore masks, socially distanced, washed their hands, followed stay-at-home orders. "In that case there is a significantly reduced risk of infection," he said.

But there are always trade-offs and temptations to defect from the regimen. Masks are annoying. Hand-washing is tedious. You need a hug.

"The pandemic is a prisoner's dilemma game played out repeatedly," Dr.

Bauch said. In lectures, he invokes a comparison between Ayn Rand, who made a virtue of selfishness, and the "Star Trek" character Spock, who said, "The needs of the many outweigh the needs of the few."

Now the vaccine adds one more protective layer. The perceived benefits and costs of vaccination are often expressed as concerns about safety and side effects. If you are on the fence about vaccination, you might decide — noticing lower infection rates as vaccination campaigns gain speed — that it no longer seems so critical to get the jab.

"Some people might play a 'wait-and-see game,'" Dr. Bauch said. People who choose not to be vaccinated effectively get a free ride, reaping the benefits of reduced virus transmission generated by the people who do opt for vaccination. But the free rides generate a collective threat.

"That is the prisoner's dilemma," Dr. Bauch said. When infection levels are low, people feel less at risk, let down their guard, and then infection levels again rise; the ebb and flow between our behavior and the virus causes the pandemic waves. "We end up in this unhappy medium," he said.

Tragedy of the commons

John von Neumann, a mathematician. left, and the economist Oskar Morgenstern, who developed the idea of game theory.Corbis, via Getty Images, left; Ralph Morse/The LIFE Picture Collection, via Getty Images

The origins of game theory can be found in the 1944 book "Theory of Games and Economic Behavior," by the mathematician John von Neumann and the economist Oskar Morgenstern. The applications range from evolution to psychology to computer science; there's even a book called "The Game Theorist's Guide to Parenting."

Dr. Bauch did pioneering work combining game theory and epidemiological modeling, with colleagues including Alison Galvani, an epidemiologist and the director of the Yale Center for Infectious Disease Modeling and Analysis.

“Vaccination decisions based purely on self-interest can lead to vaccination coverage that is lower than what is optimal for society overall,” Dr. Galvani said in an email.

The self-interest strategy maximizing individual payoff is called the Nash equilibrium. Dr. Galvani’s later research included psychological data and demonstrated that vaccination decisions can be influenced by altruism, thereby boosting uptake beyond the Nash equilibrium and serving the common good.

She noted, however, that game theory assumes people are rational in their decision-making. Fear can suppress vaccination “to precarious levels insufficient to prevent the spread of an outbreak,” she said.

A 2019 investigation using game theory to study vaccination showed that vaccine hesitancy could be explained by a mathy mechanism called “hysteresis.” In general terms, hysteresis occurs when the effects of a force persist even after the force is removed — the response lags. Paper clips exposed to a magnetic field still cling together after the field is turned off; unemployment rates can remain high even in a recovery economy.

Similarly, even after a vaccine is deemed safe and efficacious, uptake rates often remain low.

“The hysteresis effect makes the population hysterical, or sensitive, to the perceived risks of the vaccine,” said Xingru Chen, a doctoral student in mathematics at Dartmouth College, and the paper’s co-author, with her adviser Feng Fu, a mathematician and biomedical data scientist (who recently applied a similar approach to the dilemma of social distancing).

“It boils down to a fundamental problem known as the tragedy of the commons,” Ms. Chen said. “There is a misalignment of individual interests and societal interests.” To overcome the hysteresis effect, she said, vaccination should be promoted as an act of altruism — one’s personal

contribution to defeating the pandemic.

A subsequent iteration of the coronavirus game-theory study explored how vaccine compliance affects the number of deaths prevented. If a small subset of the population chooses not to get the vaccine, it affects us all, said Dr. Anand, who is also an author and a poet. Her book "A New Index for Predicting Catastrophes" includes found poems composed of words from her scientific papers.

(One poem, "The Strategy of the Majority, " was drawn from her first paper on human-environment systems, which inspired the current study. The last line: "the price of finding equilibria is increasing.")

Sebastian Funk, an infectious disease epidemiologist at the London School of Hygiene and Tropical Medicine, said that the coronavirus study nicely highlighted the importance of assessing how interventions aiming to contain spread during an outbreak can affect human behavior. "Excluding this from models of infectious disease transmission can be a major limitation," he said.

Dr. Funk and others have investigated how spreading awareness can shift the shape of epidemics.

Infectious disease models usually fail to appreciate the flux of human behavior, treating it instead as a constant, Dr. Bauch said. But, he added, it's not as if humans are too complex to model: "I see that point of view as a last vestige of the idea that 'humans are special,' from the time when we thought the earth was the center of the universe."

In his lectures, Dr. Bauch invokes Ayn Rand, who made a virtue of selfishness, versus Mr. Spock, who said, "The needs of the many outweigh the needs of the few."Bettmann/Getty Images, left; Allyn Baum/The New York Times

While holed up at home, Dr. Anand and Dr. Bauch oversaw some pandemic research by their children, 11 and 13, who produced a series of "adults get schooled" videos. The first explored the mathematics behind flattening the curve, the latest explains how to make a simple epidemic model with Google

spreadsheets.

Meanwhile, their student Mr. Jentsch had just submitted a paper applying game theory to invasive species, looking at the spread of the emerald ash borer, an invasive beetle. Dr. Anand and Dr. Bauch suggested that he next aim the game theory model at Covid-19 vaccination prioritization.

Vaccines can work in two ways.

“Direct protection” protects people who get vaccinated — for example, those who are high-risk, such as health care and essential workers, people with underlying medical conditions and older adults. In terms of direct protection, the study focused on people over 60 years old.

“Indirect protection” protects the contacts of people who are vaccinated; the high-risk population is shielded by vaccinating the individuals who are most likely to transmit the virus, such as younger people, even if they are themselves less vulnerable to the disease.

The study’s methodology combined two types of models. One was an epidemiological model of virus transmission, a workhorse used for decades that factors in things like seasonality, susceptibility to infection according to age, and variations in the vaccine’s performance.

The other, a game-theory model, factored in human behavior, and drew on Google data that revealed who went where and when in Ontario from March to November. This data was used as a proxy, approximating how stringently people adhered to social distancing and other public health advice over time.

The researchers first did a test run of sorts for their combined model, comparing it to the timeline of the pandemic waves so far, March through November. They found a good fit; the model’s projections accurately mirrored our behavioral reality: As Covid-19 cases increased in the spring, the time that people spent at retail, recreation and workplace destinations

decreased; over the summer cases trailed off slowly, not abruptly, indicating that as people saw the peak flattening they relaxed their guard.

This shows "that you can model human population behavior with simple models," Dr. Bauch said.

Then the researchers ran their model to see what lies ahead — specifically, to project the effectiveness of the different approaches to prioritizing vaccinations.

The model found that if vaccines are available sufficiently early in the pandemic, say January to March 2021 (with 2.5 percent of the population vaccinated per week), then direct protection would prevent more deaths. But if vaccines are not available until later, say July to September, by which time there is more natural immunity, then indirect protection would be more effective at reducing mortality.

(Of course, there are limitations to the model's predictions, and certain provisos. Perhaps most crucially, the study assumes that the Covid-19 vaccines block not only disease but also transmission — this is still an unknown.)

They also ran a version of the conventional model alone, not factoring in human behavior modeled from the Google data; instead, behavior was assumed to be constant.

In this scenario, the timing of pandemic waves turned out to be very different; factoring in how people behaved had a big impact on estimates of how many people got infected over time and, in turn, the most effective vaccination strategies.

Incorporating game theory, Mr. Jentsch said, injects an interesting dose of "realism." It captures how people respond to the ups and downs of daily existence, and how our actions in turn make all the difference. An army of

umbrellas won't change the weather, but vaccination can be a powerful force in defeating the coronavirus.

Vaccination campaigns now underway in Canada and the United States follow the direct protection approach. Because the coronavirus is more widespread south of the shared border, "the best time for the 'switch' to indirect protection may occur sooner in the U.S.," Dr. Bauch said.

Also, he noted, "indirect protection could be a useful route for low- and middle-income countries who will not get the vaccine as soon as wealthy countries."