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Michael A. Lewis
Hunter College School of Social Work

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COVID-19, Vaccines, and Decision Theory

Michael A. Lewis

The Silberman School of Social Work at Hunter College, New York City, USA
michael.a.lewis@hunter.cuny.edu

Synopsis

In this piece, I delve into some thoughts I've had about decision theory. These have been inspired by the vaccine rollout phase of the COVID-19 Pandemic. I focus on decision making under uncertainty, as it relates to the decision to get vaccinated or not.

COVID-19, in addition to being a deadly pandemic, has also been a seminar on the significance of mathematics for understanding real-world events. As experts have tried to understand, and help the rest of us understand, what's been going on, mathematical modeling, exponential growth, probability theory, Bayes theorem, and a host of other topics have gotten their due.

As I write these lines, about 63% of the U.S. population is fully vaccinated against COVID-19 (COVID) [6]. The U.S. is also in the midst of a recent surge in COVID cases which has apparently been caused by the highly transmissible Omicron variant of the virus. Since entering office, President Biden has pleaded with Americans who're not yet vaccinated to get a shot (or two, as the case may be) [5]. Yet many people are very reluctant to get vaccinated.

There's evidence that some of this reluctance is due to partisanship, with a higher proportion of Republicans than Democrats saying they don't plan to get vaccinated [4]. But partisanship probably doesn't explain all of it. That's because there's also evidence that vaccine hesitancy is due to concerns about their safety. That is, some appear to believe that vaccines against COVID may prevent the worst of COVID by creating health problems of their own [4]. Apparently, these folks would rather take their chances with COVID, in a "devil you know" sort of way. As I've considered all this, I've thought about another area of mathematics which is relevant to the COVID mess: decision theory.

Decision theory is an area of study which focuses on how agents (natural agents like people or artificial ones like computers) do or should make decisions. The centering of how agents do make decisions is called "descriptive decision theory," while the focus on how they should make them is referred to as "normative decision theory." Another distinction decision theorists make is between decisions made under certainty versus those under uncertainty [1].

A decision under certainty is one where the agent knows for sure the outcome of a given act. A person trying to decide whether to buy an ice cream cone might reasonably be modeled as facing a decision under certainty, assuming it makes sense to think that such a person knows for sure that handing money over to the cashier will definitely result in an ice cream cone being given to them.

A decision under uncertainty is where the agent doesn't know for sure the outcome of a given act. This is the situation those deciding whether to get vaccinated against COVID are facing.

To get a bit more precise, in order to model a decision under uncertainty, the modeler needs to do at least four things: 1) specify who the agent is or agents are 2) specify the possible acts the agent/agents may choose to engage in, 3) specify the possible states of the world (that is, the uncertain outcomes which may occur) and 4) specify the payoffs to the agent/agents under all possible combinations of acts and states. When it comes to many models of uncertainty, a fifth thing is done: probabilities are associated with the possible states of the world. One of the most common ways of presenting models in decision theory is through the use of tables [1].

In Table 1 below, I provide an example of all this by modeling the decision facing those trying to decide whether to get vaccinated, the agents in the model. The possible acts are 1) get vaccinated or 2) don't get vaccinated. The possible states of the world are 1) contract COVID or 2) don't contract COVID. The payoffs from the combinations of possible acts and states are in the cells of the table and, hopefully, self-explanatory. All of the statistics that we've kept on COVID, vaccine efficacy and effectiveness, etc. notwithstanding, I suspect that many people find it difficult to assign probabilities to the possible payoffs in the table. That is, I suspect that many are deciding whether to get vaccinated, or not, without appealing to precise numbers representing their beliefs about the probabilities of contracting COVID, suffering some adverse health effect as a result of getting vaccinated, etc.

	Contract COVID	Don't Contract COVID
Get Vaccinated	Likely mild or asymptomatic COVID infection, unlikely to be hospitalized or die from it, possible bad health effects of vaccine (a)	Possible bad health effects resulting from vaccine (b)
Don't Get Vaccinated	Perhaps mild or asymptomatic COVID infection but more likely to be moderate or severe and more likely to be hospitalized or die from it, no possible bad health effects from vaccine (c)	No possible bad health effects resulting from vaccine (d)

Table 1: A Decision Model for Getting Vaccinated. The letters in parentheses will be used below to refer to cell payoffs.

When trying to model decisions under uncertainty where agents may find it difficult to assign probabilities to various outcomes, decision theorists have come up with a number of ways of representing how agents might, or should, make decisions in such situations.

First, these theorists make assumptions about agents' preferences. Given the table above, for example, we might assume that agents prefer payoff (d) to (b), (b) to (a), and (a) to (c). That is, $(d) > (b) > (a) > (c)$, where ">" stands for "is preferred to." Even if you don't agree with this preference ranking, assume it for the sake of illustration.

One of the concepts decision theorists use to represent how people might or should make decisions is the "maximin criterion" [1]. This criterion says that a decision maker chooses, or should choose, the act that generates the largest possible minimum payoff. Let's see how maximin applies in this case.

First, focus on the "get vaccinated" row. Since payoff (b) is preferred to payoff (a), (a) is the minimum possible payoff for someone who chooses to get vaccinated. Next, consider the "don't get vaccinated" row. We see from the preference ranking, $(d) > (b) > (a) > (c)$, that payoff (d) is preferred to (c)

(I'm assuming transitivity of preferences, a common assumption in decision theory). So, (c) is the minimum possible payoff for someone who chooses not to get vaccinated.

Now compare payoffs (a) and (c); since (a) is preferred to (c), (a) is the one which meets the maximin criterion. That is, payoff (a) is the largest possible minimum one.

Those of us who've chosen to get vaccinated may, at least implicitly, have appealed to maximin in order to make our decisions. How might decision theory capture the decisions of those who've chosen not to get vaccinated? One possibility is the "maximax criterion" which says that agents should or do chose the act which generates the largest possible maximum payoff [1].

Looking back at our table, payoff (b) is preferred to (a) and (d) is preferred to (c). So, the maximum payoff of getting vaccinated is (b) and of not getting vaccinated is (d). And since payoff (d) is preferred to (b), the largest possible maximum is payoff is (d). That is, the act which meets the maximax criterion is the choice not to get vaccinated.

One thing I should point out is that, so far, I've assumed that decision makers care only about payoffs to themselves. Obviously, the choice to get vaccinated or not doesn't just affect the person making the choice but impacts others who might come into contact with them as well; that's what the concept of "herd immunity" is all about. To the extent that my model is meant to represent choices people are actually making and the extent to which people in the real world consider the effects of their vaccine choice on others, this is a serious limitation of the model.

I said earlier that decision theory is partly normative and, therefore, addresses how agents, when faced with uncertainty, should make decisions. Neither maximin, maximax, nor any other decision-making criterion in situations such as this one has received unanimous consent among decision theorists. That is, as far as decision theory is concerned and assuming my model closely approximates the decision situation agents are currently facing, it isn't clear that those who've decided not to get vaccinated are behaving irrationally. Part of the decision situation agents are currently facing has to do with incentives for getting vaccinated. Such incentives affect the payoffs agents receive from different combinations of acts and states of the world.

When COVID vaccines were first being rolled out, not many institutions required people to get vaccinated. That has changed as some employers, colleges, and universities are requiring vaccines or boosters. How might vaccine mandates change the decision situation people would face?

Take a look at Table 2 below:

	Contract COVID	Don't Contract COVID
Get Vaccinated	Likely mild or asymptomatic COVID infection, unlikely to be hospitalized or die from it, possible bad health effects of vaccine, avoid loss of job or opportunity to attend college (a)	Possible bad health effects resulting from vaccine, avoid loss of job or opportunity to attend college (b)
Don't Get Vaccinated	Perhaps mild or asymptomatic COVID infection but more likely to be moderate or severe and more likely to be hospitalized or die from it, no possible bad health effects from vaccine, loss of job or opportunity to attend college (c)	No possible bad health effects resulting from vaccine, loss of job or opportunity to attend college (d)

Table 2: A Decision Model for Getting Vaccinated When There Is A Vaccine Requirement. The letters in parentheses will be used below to refer to cell payoffs.

This is similar to Table 1 from earlier but differs by including the possibility, should one refuse to get vaccinated, of losing a job or the opportunity to attend college. That is, I've assumed that all public and private sector employers, as well as all colleges, have required people to get vaccinated; those who didn't get immunized wouldn't be allowed to work in the formal economy or attend college. How might such requirements affect people's vaccination decision?

Presumably, the hope of those advocating vaccine mandates is that the following preference ordering is the one decision makers would be acting on: $(b) > (a) > (d) > (c)$. This would mean that if one chose vaccination, $(b) > (a)$, and if they chose non-vaccination, $(d) > (c)$. Since $(a) > (c)$, those deciding on the basis of the maximin criterion would choose to get vaccinated. Given that $(b) > (d)$, people deciding on the basis of the maximax criterion would also choose vaccination. That's because such folks, in a world where they didn't end up with COVID, would rather face the possible negative health consequences of a vaccine but keep their jobs or the opportunity to go to college, than avoid such health consequences but lose the chance at a college education or livelihood.

Whether a wave of vaccination mandates will ripple across the country remains to be seen. If so, as someone interested in decision theory, I'll be watching closely.

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Author bio:

I'm a social worker and sociologist by training; I have a Masters' degree in social work and a PhD in sociology. By accident, I became interested in applied mathematics. I wanted to learn economics, realized that I didn't have the math background to do so, and taught myself the math I needed to know. It would be a huge stretch for me to call myself a mathematician, applied or otherwise. I have a friend who is a well-known applied mathematician, and I simply cannot do what he can. But that hasn't stopped me from loving mathematics and trying to apply it as much as my skill level and the social work schools where I've taught have allowed me to get away with [2, 3].