The Dangers of Unmonitored Group Decision:

Vaccination Games

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Introduction

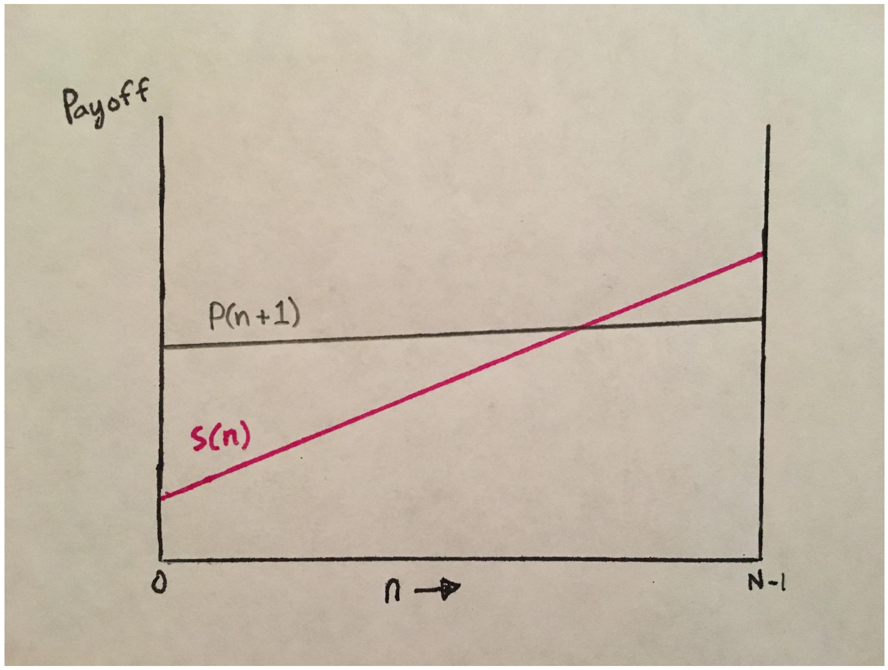
The purpose of vaccinations is to provide disease immunity to individuals. Vaccinations have led to the near eradication of many dangerous diseases that used to harm populations across the world. In recent years, however, an increasing number of near-eradicated diseases such as measles, rubella, and polio-like diseases have been appearing. Along with these cases, we're hearing a lot more about people who have apparently stopped getting vaccinations for themselves and their families in fear of negative health consequences. So, is there really a growing number of people refusing vaccinations and subsequently putting the general population at a higher risk? The prediction this paper seeks to support is that these vaccination games result in vaccination coverage that is not optimal in the absence of policy intervention.

By modeling this situation with the help of game theory, the public issue of vaccination coverage can be analyzed in a way that explains the decisions made by individuals. Vaccine effectiveness for a given group depends on what is known as "herd immunity." That is, enough of a population is vaccinated that a disease's ability to spread is significantly decreased, even among those who don't or can't get vaccinated. Although no vaccine is completely effective at stopping transmission, vaccination significantly decreases the ability of disease to transmit between individuals. There always exists a subset of the population that is not receiving vaccinations, either because they cannot (the immunocompromised) or they can, but refuse to. Since a disease has a greatly reduced ability to spread in a population that is heavily vaccinated, those who aren't vaccinated also have a greatly diminished risk of infection.

Game Model

The purpose of this paper is to demonstrate vaccination decisions and outcomes through the lens of a collective-action game. More specifically, this game is modeled after a "Large Group Chicken" collective-action game. Collective-action games typically have a large number of players and the choices of individuals have an impact on the benefit of the group as a whole. An important aspect of collective-action games is that the optimal outcomes for the group are not always in the best interest of each individual's private interests. In the case of vaccinations, there are a large number of players (the population group), who are all making decisions of whether or not to vaccinate. Herd immunity is both non-excludable and non-rivalrous, making it a public good. Many public goods often give rise to a "free-rider problem," that is, people receiving the benefit from a good without paying for it. Herd immunity is no exception, as it is also a good usable by those not contributing towards it. Given that the free-rider problem exists within this game, it can be expected that the nash equilibrium will not be the socially optimal outcome.

In order to construct this model some variables must first be denoted. The cost that participants (vaccinated) will incur is represented by $C(n)$, with n denoting the number of participants. $B(n)$, is the benefit each player receives, regardless of whether or not they chose to participate. Therefore, a participating player receives $P(n) = B(n) - C(n)$ in payoff, while a non-participating player receives $S(n) = B(n)$ in total payoff. Knowing these payoff functions, to solve for the model we set $P(n + 1) = S(n)$.



When analyzing large group problems through game theory, a given player will choose to contribute at any point where $P(n + 1) > S(n)$. As exemplified through collective-action games like Chicken, the nash equilibrium is reached at one point, where $P(n + 1) = S(n)$. Once this point is reached, the benefits of being the next to participate are outweighed by the payoffs of not participating. This model would suggest that this equilibrium point is reached once the "herd immunity threshold" for a given disease is achieved. This predicts that players will always choose to vaccinate when the population coverage is below the threshold [$P(n+1) > S(n)$] because, while the disease is more easily spread, the vaccine greatly reduces their risk (shifting participation up). The opposite is predicted whenever the population participating is above the threshold [$P(n+1) < S(n)$]. This is because once herd immunity is achieved, the risk of catching the disease is hardly different between vaccinated and unvaccinated subsets of the population, meaning additional participants incur an added cost with little to no added benefit (shifting participation down)..

The equilibrium prediction that populations will vaccinate around the point where the herd immunity threshold is met hinges on several basic assumptions: full player rationality, symmetric costs and benefits, and no other regarding preferences. Throughout the following cases, these assumptions will be examined to determine whether or not the equilibrium prediction can be reached in real-world vaccination games. Net social benefits can be achieved once herd immunity is met, and can only increase as more participate as more vaccine coverage leads to gradually decreasing disease incidence.

Case Studies

The issue with determining whether or not the equilibrium prediction is being played, is that the expected outcome is that most individuals will get vaccinated while some will not. This is an issue because that is the outcome of all vaccination games, but that alone doesn't necessarily mean the equilibrium is being reached. What will determine if players are making decisions that lead to the equilibrium prediction is whether these decisions satisfy the model's underlying assumptions. Since the equilibrium prediction is only able to be made under the assumptions of full rationality, symmetric costs and benefits, and no other regarding preferences, violation of these assumptions would indicate unreliability of our model's prediction on real-world vaccination games. The applicability of these assumptions in our model will be analyzed in the following case studies.

The first case we look at is "Group Interest Versus Self-Interest In Smallpox Vaccination Policy" by Chris T. Bauch, Alison P. Galvani, and David J. D. Earn. This case looks into how individual interests differ from group interests by analyzing this idea alongside smallpox vaccination policy. After a worldwide vaccination campaign throughout the late 50s and 60s, smallpox was officially declared eradicated by the World Health Organization in 1979 [8]. This case analyzed historical infection data to make predictions about how individuals would behave should a smallpox outbreak occur today and also analyzed vaccination policy. Specifically, this case seeks to see if there's a difference in outcome when government mandated smallpox vaccination is compared to voluntary vaccination. In this situation, individuals are choosing to either get vaccinated or to not vaccinate, and undertake the risk of infection. It fits with our game because the policies being examined demonstrate what will happen if a population is acting purely in self-interest in respect to vaccination decisions.

From the beginning of this case, they note that if vaccinations were entirely voluntary in the case of smallpox, it would be "difficult to maintain" high levels of vaccination coverage. They state this is so due to the fact that an individual doesn't have much to gain from a vaccination "if everyone else is already immune." [2] This is already shown in the equilibrium prediction, but this case presents another, less obvious issue. Vaccination games are particularly complex, as there is an assumption that players have close to or "complete knowledge of the risks." In other words, there is the assumption of full rationality; that players are fully informed and behaving rationally in order to maximize their individual payoffs. Yet, this case still predicts a much lower vaccination coverage than what's predicted by our model. The case indicates that the full rationality assumption is violated, which in turn would lead to lower vaccination participation than equilibrium (herd immunity threshold). One of the biggest dangers to preemptive vaccine coverage of previously eradicated disease, is the public's perception of risk.

Frankly, because of how successful many vaccine programs have been, the public has little to no experience with certain diseases and creates a false perception of low risk.

Not only does this false perception lead certain players to make decisions that are deemed as irrational, but this also leads to asymmetric costs and benefits between players. In a game where every player had realistic perception of the costs and benefits (as predicted in the model), we would expect the outcome to be as predicted: equilibrium at the herd immunity threshold. In this realistic situation, however, this mismatch in perception makes it so certain players underestimate the benefit of vaccines and overestimate their costs. This would violate our symmetric cost and benefit assumption and also cause players to fall short of the estimated nash equilibrium predicted in the model.

The second real-world case makes the opposite argument. That voluntary vaccination programs have potential to reach more efficient outcomes based on communication within communities. This case relates to our game in that it discusses the differences in individual and group payoffs in relation to vaccination games. How this case differs, is that it takes into account social networks and their impact on vaccination decisions. Whenever an epidemic affects a given population, players receive both "local information about the number of [local] infected cases" as well as "global information about the disease prevalence." [6] The paper makes the argument that once a disease has begun impacting a player's "local network," news spreads much faster through word of mouth and social networks. These changes "evolve" payoffs for these local players as an epidemic progresses. That is, although individuals may be playing below the equilibrium prediction initially, through communication they can quickly adjust to playing the equilibrium. As opposed to the previous case, players become more aware of the risk as the disease incidence grows, making their perception of the disease more realistic to the payoffs that are expected from the model, making the full rationality assumption more attainable in a real-world setting.

Given how populations are made up of many different types of people, it's assumed that "all individuals are provided with the same information and use this information in the same way to assess risks." (Bai, Fan. Journal of Biological Dynamics)[1]. This case is therefore suggesting that the costs and benefits to players would be symmetric, especially when compared to other cases. The assumption of no-other regarding preferences could also be argued to be met, as most individuals would seek to vaccinate for personal benefit, regardless of other players' outcomes. The assertions made by this case would indicate that it is indeed possible that populations could be playing the equilibrium prediction made by this paper's model. However, the results of this case aren't shown to be applied to all population groups and in all likelihood aren't representative of what's possible in many populations. If these cases can be shown to be applied to local communities worldwide, this would indicate payoff decisions closer to the model presented in this paper however.

The final case being examined is a real-world example that presents the behaviors of vaccine skeptics and vaccine believers observed in relation to measles. In this example, we observe the increasing number of measles cases in the United States, even though "endemic transmission of measles was declared eliminated in the US in 2000." [2]. This case relates to our game in that it analyzes the possibility of different cost/benefit perceptions between individuals choosing whether or not to get vaccinated. The article states that it's believed that a lack of personal experience of dealing with measles, led many parents to begin refusing vaccinations for their children. This case is unique in that certain players are choosing to forgo vaccinations, not because they believe enough people are vaccinated, but because they believe vaccines have little to no benefit whatsoever.

As this case describes an actual resurgence of a previously "eradicated" disease in a population, we can expect relatively large violations of our nash equilibrium model assumptions. For vaccine skeptics, it is likely that their perceived payoffs from not participating are almost, if not always, higher than getting vaccinated [$S(n) > P(n+1)$, for all n]. These payoffs are completely different from those expected to participate up to the equilibrium prediction. The cost and benefits vary widely between players, and this enormous underestimation of vaccination benefits by skeptics pushes participation below the equilibrium prediction (violating the symmetric cost/benefit assumption). As for the assumption of no other-regarding preferences, this too is violated greatly. According to the World Health Organization, many of those opposed to vaccination believe that vaccines can actually cause you to get the disease [9]. Misinformation such as this, as well as other beliefs that vaccines do more harm than good lead these individuals to have preferences to discourage other individuals from getting vaccinated as well. Perhaps the most noticeable assumption violation is that of full rationality. An increasing subset of players have completely opposite perceptions of vaccination coverage, causing them to make decisions with payoffs far worse than if they'd behaved rationally.

The introduction of a sizable population subset of vaccine skeptics into vaccination games leads to results far below the equilibrium prediction we'd expect from vaccination games with full rationality, symmetric costs/benefits, and no other-regarding preferences. According to the article, without public health intervention, individuals will establish a "vaccination strategy that will maximize personal payoff," only taking account of the current "disease incidence and risk of infection," [2]. Because herd immunity is able to be effective without every person receiving a vaccination, individuals who choose not to vaccinate, have received the same benefit that those who do vaccinate in recent years. This misplaced perception of security has led to varying perceived payoffs that players receive from choosing whether or not to be vaccinated.

Conclusion

Populations have abundant access to accurate information about the risks associated with past disease. Oddly enough, it is mainly due to our past success in nearly eradicating many diseases that has led to many individuals misjudging the dangers of these diseases and their ability to reappear. This lack of experience has led to many players adopting inaccurate perceptions of the risks they face by refusing vaccinations. Given that players have a perception of low risk, they overestimate the payoffs they would receive from not participating.

The nash equilibrium prediction presented by this paper is likely not able to be met without vaccination policy intervention. This is due to the failure of real-world vaccination games in meeting the assumptions of full rationality, symmetric costs/benefits, and no other-regarding preferences. Knowing these issues with vaccination games left up to self-interested individuals, intervention would be necessary in order to make some vaccinations mandatory for the vast majority of the population, educate the public to discourage vaccine skepticism, and provide an accurate perception of possible risks. Although the model presented is held back by the interference of other variables, it provides a goal for intervention solutions to reach in order to get closer to being socially optimal.

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