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The Effects of Differences in Vaccination Rates Across Socioeconomic Groups on the Size of Measles Outbreaks

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Abstract. Vaccination rates are often presented at the level of a country or region. However, within those areas there might be geographic or demographic pockets that have higher or lower vaccination rates. We use an agent-based model designed to simulate the spread of measles in Irish towns to examine if the effectiveness of vaccination rates to reduce disease at a population level is sensitive to the uniformity of vaccinations across socioeconomic groups. We find that when vaccinations are not applied evenly across socioeconomic groups we see more outbreaks and outbreaks with larger magnitudes.

1 Introduction

Although many countries in the world have eliminated some endemic childhood diseases such as measles, imported cases still are a threat especially when vaccination rates are not ideal. While a region or country might have a high vaccination rate this vaccination rate is not always even across the population with certain groups having lower vaccination rates. In particular it has been shown that in Ireland, vaccination rates for childhood diseases vary by socioeconomic status (Doherty et al., 2014). This can lead to pockets of unvaccinated individuals. We examine whether the effectiveness of vaccination rates in a population are sensitive to the uniformity of vaccinations by investigating whether the existence of such pockets causes a difference in the size and number of outbreaks compared to a population where vaccinations are uniform across socioeconomic groups.

2 Methodology

We use an agent-based model to simulate the spread of measles in Irish towns (Hunter et al., 2018a) to investigate how different distributions of vaccination rates across socioeconomic groups affect outbreaks. We run the model for 3 different towns: Schull, Kilkee, and Tramore and two vaccination levels: herd immunity for measles and real Irish vaccination rates. We calculate the level of vaccination needed for herd immunity using the equation for the critical vaccination coverage:

$$V_c = \frac{(1 - \frac{1}{R_0})}{V_e} \tag{1}$$

where V_e is the vaccine effectiveness rate, V_c is the critical vaccination coverage or the proportion of individuals who need to have been vaccinated to achieve herd immunity when we take vaccination effectiveness into account, and R_0 is the basic reproduction number. For each vaccination level we run two scenarios: vaccination rates are evenly distributed across all socioeconomic groups and vaccination rates are assigned using data from an Irish study showing the uptake of childhood vaccination rates by socioeconomic status. We run the model 100 times and compare the output.

3 Irish Vaccination Rates

With Irish vaccination rates, we look at the mean of total infected agents and the distribution of total infected agents across the 100 runs and compare these for the scenarios with uniform vaccination rates and vaccination rates determined by socioeconomic status. The mean of total infected is greater in the simulation runs where vaccination rates are adjusted by socioeconomic status. Table 1 shows the means for each vaccination scenario for each town and the p-value for a one-sided difference in means t-test.

Table 1. Mean Infected for Vaccination Scenarios with Irish Vaccination Rates

	Schull	Kilkee	Tramore
Uniform	13.54	14.48	47.88
Socioeconomic	19.57	24.28	85.97
p-value	0.004	5.6e-5	9.4e-5

Using Wilcox-Rank Sum test to determine if the distributions of total infected are different between vaccination scenarios we find that there is a significant difference between vaccination scenarios for all three towns.

4 Herd Immunity

With herd immunity, we do not see a large difference in the means or the distribution of infected as the outbreaks are much smaller under herd immunity but we do see a significant difference in the proportion of runs where outbreaks occur (the initially infected agent infects at least one other agent), with a greater proportion of outbreaks in the model with vaccinations by socioeconomic class for Schull and Kilkee and no significant difference for Tramore. Table 2 shows the percent of runs that lead to an outbreak for each vaccination scenario for each town and the p-value for the one-sided t-test for the proportion of outbreaks with uniform vaccination rates less than the proportion of outbreaks with socioeconomic vaccination rates.

Table 2. Mean Infected for Vaccination Scenarios with Vaccination to Herd Immunity

	Schull	Kilkee	Tramore
Uniform	40	34	85
Socioeconomic	57	47	84
p-value	0.01	0.04	0.50

5 Conclusions

Our results show that when vaccinations are not applied uniformly across socioeconomic groups more outbreaks and outbreaks of a larger magnitude might occur. With an increase in measles cases due to lower than desired vaccination rates around the world it is important to understand how differences in vaccination rates might affect a resulting outbreak. It may be important to focus on policies that target those in socioeconomic groups with traditionally lower vaccination rates and understand why these rates are lower in order to protect these groups and the larger population. Additionally, while we show that differences in vaccination rates by sub groups can have an impact on outbreaks, this effect might be magnified if those groups with lower vaccination rates are living in clusters together. The work by Hunter et al. (2018b) shows the when agents' home locations are clustered based on their socioeconomic status we see an even bigger effect on outbreak size. Future work in this area will involve looking more closely at the differences in socioeconomic groups in each town. For example, do we see differences in outbreaks for towns with different socioeconomic distributions. We can also look at larger geographic areas besides towns, potentially looking at the impact of uneven vaccination rates at the county level or the country level. Additionally work could be done looking beyond childhood diseases, such as measles, to study the impact of uneven vaccinations for influenza or COVID-19 and how groups of unvaccinated individuals might lead to outbreaks or a continuation of the pandemic even if the majority of the population are vaccinated.

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