The spatial and social clustering of vaccine refusal: An agent-based modeling approach

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In early 2008, a measles outbreak occurred in San Diego, California. Notably, the San Diego outbreak was able to spread through two generations of secondary infection due to a cluster of unvaccinated children in the same school—children whose parents had decided that the risks of vaccines outweighed the risks of vaccine-preventable diseases, and who constituted a tight social network of like-minded families. For the measles virus, this was an ideal environment. The outbreak eventually totaled 12 cases, and resulted in dozens of children undergoing mandatory quarantine.

Recent measles outbreaks have been characterized by a lower percentage of imported cases, as outbreaks are able spread through a larger population of susceptible (unvaccinated) children in this country (see Figure 1). Exemptions from the required childhood immunization schedule have increased in the past decade with growing parental concerns about the safety of vaccines and their alleged connection to autism and other health risks. Increased vaccine refusal rates have led, in turn, to more frequent outbreaks of vaccine-preventable diseases such as measles that had previously been all but eliminated in the US (see Figure 2). Understanding how parents make the vaccination decision on behalf of their children is an important component of childhood infectious disease prevention policies. In this paper, I will use multiple data sources to inform an agent-based model of the vaccination decision and the resulting spatial and social clustering of unvaccinated children within certain neighborhoods, schools, and physician practices. This clustering has implications both for the risk of disease outbreak and policy and program interventions to preserve herd immunity.

The model will be populated by agents (parents) who are assigned characteristics including vaccination preferences, preference strength, degree of influence on others, propensity to socialize with other parents, social homophily (preference for mixing with like-minded parents), school choice, and physician practice. In each tick of the model, agents will make decisions about adhering to the vaccination schedule, changing to a new physician practice, changing to a new school, and socializing with other agents. Decision rules will be based on the agent's characteristics as well the characteristics of nearby agents, physicians, and schools. For example, an agent may prefer to go to a physician who has a high tolerance for vaccine refusal and who also has a high proportion of refusing patients. Agents may change to a new physician practice accordingly. Similarly, agents may socialize with other agents who may influence future vaccination preferences and eventual decisions.

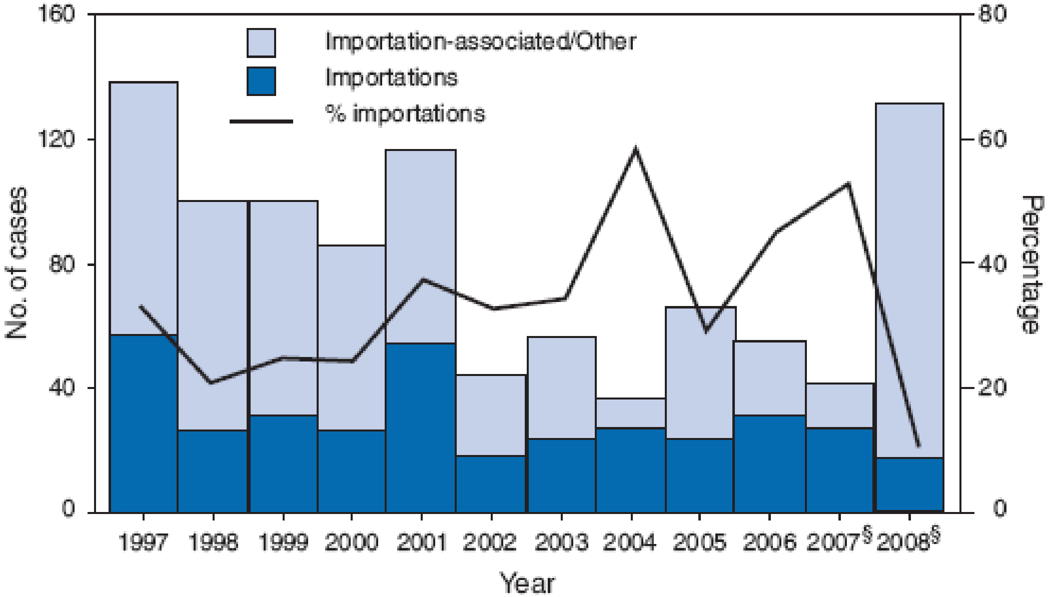
Initial distributions of agent, physician and school characteristics will be based on several data sources. Clustering of unvaccinated children within schools will be informed by the range and spatial distribution of exemption rates in California schools, available from the California

Department of Public Health. Parental vaccination preferences by sociodemographic characteristics will be obtained from existing surveys such as the National Immunization Survey and clinic data from a large urban pediatric research consortium. The role of vaccination preferences in the selection of pediatric providers and the influence of peers in the vaccination decision will be informed by a primary qualitative and quantitative study of a neighborhood parent network and a new pediatric practice opening in the same neighborhood. Decision rules will be based on theoretical and experimental work on judgment and decision-making, including the informational biases that shape low-frequency, low-information decisions like vaccination.

The output of the model will be the spatial distribution of unvaccinated children in neighborhoods, schools and physician practices over time and under varying scenarios of agent characteristic distributions and decision rules. The model will allow for the identification of triggers or tipping points that result in particularly risky levels of non-vaccination within certain groups. Planned extensions of the model include incorporating different types of state exemption regimes (easy vs. difficult), media coverage of vaccine safety issues, and actual disease outbreaks into preferences and decision rules.

The paper will conclude with a discussion of how the model can be used to evaluate hypotheses about disease risk based on the clustering of vaccine refusal behavior. For example, if unvaccinated children mix with *under*-vaccinated children (those who have delayed or missed immunizations due to access to care rather than refusal), could rising refusal rates amplify social disparities in the risk of vaccine-preventable diseases? How well does “catch-up” immunization after an outbreak improve herd immunity? The model will also be used to test competing policy interventions related to immunization coverage. For example, if parents were made aware of exemption rates in their child’s classroom or school, and of the attendant risks to which their children were being subjected, would this change the decision-making context for reluctant parents? If adherent parents chose to frame vaccine refusal as “cheating” or as “free riding”, and this framing were persuasive to refusing parents with less strong convictions about this position, could adherence increase? Results from these tests can inform immunization policy and improve parent and physician education efforts.

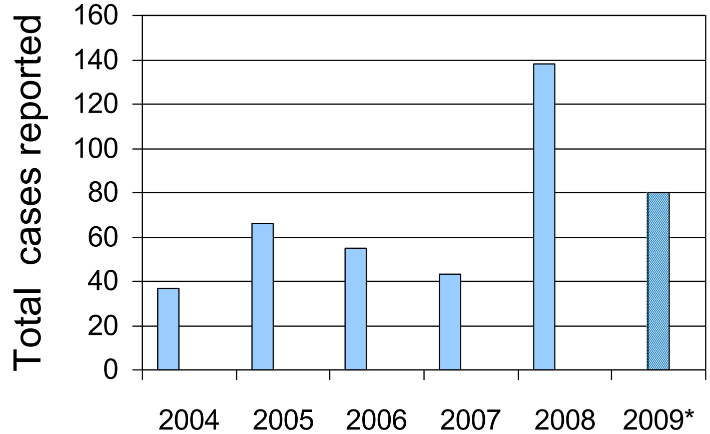
FIGURE 1. Trend in cases of imported measles* as a proportion of all measles cases† — United States, 1997–July 2008



* Measles infection acquired outside of the United States.
† Includes importation, importation-associated (acquired inside the United States but linked epidemiologically to an importation), and other (source unknown) measles cases.
§ Provisional; 2008 data are for January–July only.

Source: Measles – United States, January 1- April 25, 2008. MMWR. May 9, 2008/57(18); 494-498.

FIGURE 2: Measles Incidence, United States, 2004-2009



* Confirmed cases via MMWR through September 12, 2009, annualized