NONMEDICAL EXEMPTIONS TO VACCINATION IN ILLINOIS:
A MULTI-SCALAR ANALYSIS

A Thesis in
Geography
by
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ABSTRACT

The CDC publishes annual estimates of school-age children vaccination rates that are high at the federal-level, yet, vary significantly at lower scales. Vaccination requirements, exemption policies and data collection are mandated by individual states, leading to wide variations in compliance and difficulties in monitoring immunization levels and trends over time. At the local-scale low vaccination rates result in higher susceptibility to vaccine-preventable outbreaks; research conducted at this scale is beneficial for preventative public health efforts. However, most literature focuses on undervaccination risk factors including socioeconomic status, education level and individual preference that are helpful in detecting which demographics are most susceptible but not in determining where these populations are located. This thesis uses two cluster detection functions – Getis-Ord Gi* Hot Spot Analysis and Anselin Local Moran’s I – to identify and compare nonmedical exemption clusters in Illinois schools for two school years. The temporal analysis shows that in the span of ten years, nonmedical exemption clustering within Illinois rose and spread throughout the state. Spatial statistics are a useful tool in identifying geographic clusters of high exemption rate schools, thereby finding the locations of populations most susceptible to vaccine-preventable outbreaks.

Key Words: immunization, nonmedical exemption, anti-vaccination, hot spot analysis, Illinois, public health
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List of Abbreviations

AAP – American Association of Pediatrics
ACIP – Advisory Committee on Immunization Practices
CDC – Center for Disease Control and Prevention
DTP – Diphtheria, Tetanus and Pertussis vaccine
HiB- Haemophilus influenzae type b vaccine
HH- High-High Cluster
HHS – U.S. Department of Health and Human Services
HL – High-Low Outlier
ISBE – Illinois School Board of Education
IVAC—Illinois Vaccine Awareness Coalition
LH – Low-High Outlier
MAUP – Modifiable Areal Unit Problem
MMR – Measles, Mumps, Rubella vaccine
NME – Nonmedical exemption
NVIC- National Vaccine Information Center
NIS – National Immunization Survey
PBE – Personal Belief or Philosophical Exemption
PCV- Pneumococcal conjugate vaccine
SIDS – Sudden Infant Death Syndrome
TDAP- Tetanus, Diphtheria and Pertussis vaccine
VAERS - Vaccine Adverse Events Reporting System
VFC - Vaccines for Children Program
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Chapter 1

Introduction

The Center for Disease Control and Prevention (CDC) ranked vaccination as one of the top ten public health achievements of the twentieth century (CDC 1999b). The impact of vaccinations has been dramatic in the United States—it is one of the largest factors responsible for the decrease in incidences of infectious disease and corresponding increases in life expectancy (CDC 1999a). Scientific evidence has proven the efficacy of vaccinations to protect bodies from infectious diseases that could maim or kill and vaccines are safer and more regulated than they have ever been.

Despite the effectiveness and safety of vaccines, a measles outbreak occurred in Southern California in December 2014. Starting with an unidentified person in Disneyland, this epidemic spread to a total of 113 people in multiple states, Canada, and Mexico (Clemmons et al. 2015; CDC 2016a). The media lavished attention on this outbreak, publically pitting pro and anti-vaccination platforms against each other. Questions about vaccination rates for children arose in mass-market news outlets such as National Public Radio, USA Today and the New York Times (Keller, Bloch, and Park 2015; National Public Radio 2015; Hoyer 2015). Extra media attention may have centered on the so-called “Disneyland outbreak” because of the connection with the theme park and because of the vocal anti-vaccination community in California, which includes many celebrities. Although not as publicized as the Disneyland outbreak, successive measles epidemics in 2014 resulted in the highest number of measles cases (667) reported since the elimination of endemic measles in the United States was declared in 2000 (CDC 2016a).
Unrelated to the “Disneyland outbreak,” the first confirmed measles death in the United States since 2003 occurred in 2015 (Washington State Dept. of Health 2015). The states with the highest number of measles cases in 2015 were California, Illinois and Washington (CDC 2016a). In addition to measles, pertussis (commonly known as whooping cough) has also made a resurgence in recent years.¹ Many of the recent cases of infectious diseases have occurred in people who are unvaccinated (never vaccinated) or undervaccinated (never completed the federally recommended vaccination series).²

One factor contributing to the increased prevalence of vaccine-preventable diseases is decreased herd immunity allowing diseases to spread through an unprotected population. The term herd immunity was first coined in 1923 to differentiate between individual immunity and the immunity of a group or community. It is measured by identifying the proportion of immune persons within this select group (Topley and Wilson 1923; Fine, Eames, and Heymann 2011). The threshold for herd immunity is met when a sufficiently large percentage of the population is immune to a disease so as to prevent potential outbreaks; therefore, an outbreak is unlikely to occur because the disease cannot infect enough persons to form a base to continue spreading (May and Silverman 2003). Each vaccine requires a different percentage of the community be vaccinated to achieve herd immunity – typically ranging from 90 to 95% (Fine 1993).³

Nationally, vaccination rate levels are high⁴ but epidemics spread at the local scale, where

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¹ In the 1980s, there was an average of 2,783 reported cases of pertussis per year in the United States. The average in the 1990s was 5,678 cases and from 2000 to 2014 the average was 18,793 cases. In 2012 there were 48,277 cases – the highest number of reported since 1954 (CDC 2015b).
² It is possible for a person to be unvaccinated against one disease, undervaccinated against another and vaccinated against a third.
³ The exception is tetanus because tetanus is not contagious; as a result herd immunity has no role in protecting individuals or a community from tetanus (Fine 1993; Fair et al. 2002).
⁴ The average vaccination rate for MMR, DTP and Varicella was over 93% for kindergartners for the 2014-2015 school year (Seither et al. 2015).
vaccination levels can be much lower. Locally, herd immunity plays a large role in preventing vaccine-preventable outbreaks.

Part of decreased herd immunity can be attributed to the rise in exemptions to vaccination in schoolchildren (Feikin et al. 2000). In lieu of vaccinating their child, parents have two options: medical exemptions and nonmedical exemptions. All states permit medical exemptions for students with a medical contraindication to a vaccine or vaccine component. These are a small proportion of the total population, estimated at one half of one percent. The CDC reported that the median percentage of kindergartners medically exempt from required vaccinations for the 2013-2014 school year was 0.2 percent (Seither et al. 2014). The second option is a nonmedical exemption (NME). NMEs are further separated into religious exemptions and personal belief exemptions (PBE). Each state has a different definition of each of these, but in general, a religious exemption is requested based on a sincere (as evaluated by the state) religious belief against vaccination or a specific vaccine. PBEs have a wider range of definitions but typically involve include a parental objection to vaccination based on a personal or philosophical conviction.

NME rates vary throughout the United States. For the 2013-2014 school year, Virginia reported an NME rate of 0.4% and Oregon reported a rate of 7% (Seither et al. 2014). While state-level variations are useful, vaccination rates have most impact at the local level --vaccine-preventable diseases spread at the local scale and herd immunity is measured at the local scale. The CDC has little capacity to analyze immunization data below the state level and encourages states to identify local-scale geographic “clusters” (places where the proportion of students with NMEs is higher or lower than the general population) of both NMEs and underimmunization (Seither et al. 2013; Seither et al. 2014; Elam-Evans et al. 2014).
The study of vaccination and vaccination exemptions in the United States is multi-scalar. Federally, there is no jurisdiction over vaccination law. Federal vaccination recommendations are made by the CDC, an operating division of the United States Department of Health and Human Services (HHS). However, the CDC does not have any power to produce or enforce vaccination laws, which are created and implemented by states. Since the 1850s states have used the education system as a way to incentivize vaccination (Duffy 1978). Since 1980 all states have had compulsory vaccination laws for school attendance, resulting in high vaccination rates for school age children (and therefore their demographic cohorts as they age) (Orenstein and Hinman 1999; Salmon et al. 2006). Some states have vaccination requirements for attendance at child care facilities, but for the majority of children the first official vaccination requirement is upon starting kindergarten. At a minimum, all states require two doses of measles, two doses of mumps, one dose of rubella, three doses of diphtheria and three doses of tetanus for school entry, although most states require more vaccines and additional doses (Seither et al. 2015).

For the year 2015, the CDC recommended vaccination for 14 diseases by the time a child turns two years old (2015a). In the last 30 years, massive changes have occurred to the recommended immunization schedule for children; in 1985 a fully-vaccinated child under two had received seven vaccinations, only half as many as children receive today (Figure 1.1). Once a vaccination is recommended by the CDC, doses and age requirements often change; however, with the exception of rotavirus, once a vaccination is added to the recommendations it is not

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5 These vaccines are measles, mumps, rubella (MMR), diphtheria, tetanus, acellular pertussis (DTP), polio, hepatitis b, haemophilus influenzae type b (HiB), varicella, rotavirus, pneumococcal (PCV), influenza and hepatitis a.
removed. Rotavirus is unique because it was initially recommended in 1998, removed in 1999 due to safety concerns\(^6\), and then added again to the recommendations in 2006.

<table>
<thead>
<tr>
<th>Year</th>
<th>Vaccines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>MMR, DTP, Polio</td>
</tr>
<tr>
<td>1989</td>
<td>Hib</td>
</tr>
<tr>
<td>1993</td>
<td>Hepatitis B</td>
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<tr>
<td>1997</td>
<td>Varicella</td>
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<tr>
<td>2001</td>
<td>Rotavirus</td>
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<td>2005</td>
<td>PCV</td>
</tr>
<tr>
<td>2009</td>
<td>Influenza</td>
</tr>
<tr>
<td>2013</td>
<td>Hepatitis A</td>
</tr>
</tbody>
</table>

Figure 1.1. Timeline for CDC Recommended Vaccinations for Children Under 2 Years of Age (Data from CDC 2014a).

The United States tracks vaccination compliance at the federal levels by requiring each state to submit vaccination and exemption data for all kindergartners to the CDC. In addition, HHS sets ten year goals for health promotion and disease prevention in the Healthy People Initiative that include vaccination rate goals (Department of Health and Human Services 2015a). Healthy People 2020 target vaccination coverage for kindergartners is 95% for MMR, DTP, Polio, Hepatitis B and Varicella. Current vaccination levels are high: for the 2014-2015 school year, the CDC reported the median vaccination coverage for kindergartners as 94% for MMR, 94.2% for DTP and 93.6% for varicella. However, 32 states reported that they were below the 95% Healthy People 2020 goal, with seven states reporting below 90% (Seither et al. 2015).

Although the CDC publishes a yearly report on the vaccination rates of kindergartners, the lack of a uniform data collection process does not allow for comparisons between states or a

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\(^6\) The safety concern was an increase in the prevalence of an uncommon intestinal blockage known as intussusception in two month old children who received the rotavirus vaccine. The CDC revoked recommendation of this vaccine as soon as the correlation between intussusception and rotavirus vaccine was discovered in October 1999 (Offit 2011, 72–73).
federal-level longitudinal study of vaccination or exemption trends. The CDC encourages states
to conduct their own analysis at the state- and local-levels (Seither et al. 2015). However,
publicly available vaccination data was available in 2015 for less than half of states at the county
level or higher. Vaccination and exemption data was publicly available for only ten states in
2015.7 With the exception of Minnesota, Iowa and Illinois, these states are scattered
throughout the United States, unable to provide a regional study area for NME analysis. To
conduct a regional analysis of NMEs in Minnesota, Iowa and Illinois would be challenging and
require a NME standardization metric as each state has different reporting procedures and data
collection processes.8 Of these three states, Illinois has the most detailed archives, maintaining
vaccination and exemption data since 2003.

Current vaccination literature centers on California’s vaccination rates and NMEs partly
due to the availability of thorough data. However, there is a certain notoriety to the California
example, given the quirkiness associated with the “Left State” that often makes it seem not
representative of wider American social patterns. Consequently, instead of studying California,
this thesis analyzes vaccination exemption rates in Illinois, contributing to the growing body of
literature on vaccination exemption spatial patterns at the local-scale. Studying Illinois NME
patterns has multiple advantages including a large, diverse population that is certainly
representative of the United States. In addition, the Illinois State Board of Education (ISBE)
maintains detailed current and historical vaccination records including exemptions by vaccine at
the school-level, making it an ideal state to study vaccination exemption patterns over time.

7 The 10 states that made vaccination publicly available in May 2015 at the school level were: Arizona,
California, Illinois, Iowa, Massachusetts, Minnesota, Texas, Vermont, Virginia and Washington.
8 Iowa reports total percent vaccinated by school for all schools over 100 students (Iowa Department of
Public Health 2016). Minnesota reports kindergartners only by vaccine at the school-level (Minnesota
Department of Health 2015). Illinois reports individual vaccines by school for all students (Illinois State
Board of Education 2015e).
Thesis Structure

This thesis outlines how the current anti-vaccination movement is similar to the historical anti-vaccination movement and determines whether or not there are spatial clusters of NMEs in Illinois using data from the 2003-2004 and 2013-2014 school years. Using two cluster detection functions with two spatial weights, the locations of such clusters are identified and possible explanations sought. The research also determines if there are NME patterns and clusters unique to a specific vaccine and the advantages of each function and spatial weight are discussed. Finally, this thesis addresses the changes in NME patterns over time and the increasing polarity of vaccination exemption choice.

This thesis proceeds in five sections. The next chapter reviews literature surrounding anti-vaccination movements, and in the process uncovers similarities between the current and historical anti-vaccination movements. Illinois is then introduced as a spatial area of interest with emphasis on the history of vaccination policy within the state. The chapter concludes with a brief introduction on the vaccination data used for the statistical spatial analysis. The methods on how to test for statistically significant NME clusters, data procurement and limitations is the focus of Chapter 3. Chapter 4 presents and discusses the results of the statistical tests. It includes the locations of NME clusters, discussion of NME patterns, analysis of vaccine-specific differences and temporal changes between the 2003-2004 and 2013-2014 school year. The thesis concludes with a dialogue on the merits of each statistical test and recommendations for future research.
Chapter 2

Anti-Vaccination Sentiments in the United States: Past and Present

Introduction

For centuries, humans have invoked preventative measures to protect themselves from disease. As early as the tenth century, Chinese and Indians practiced the oldest form of preventive immunization, smallpox variolation, which is the practice of infecting a person with the live smallpox (variola) virus (Willrich 2011, 35; Fenner et al. 1988, 225). By the early 1700s forms of variolation existed across the globe including in the American Colonies (Willrich 2011, 35). The risks of variolation were serious; estimates are that the one in fifty patients died following variolation. In the eighteenth century the practice of smallpox vaccination, infecting a person with the cowpox (vaccinia) virus, emerged in the United Kingdom but was not widely accepted until after 1798 when Edward Jenner published a pamphlet on the procedure and merits of vaccination (Jenner 1798). Jenner’s recommended procedure quickly spread throughout Europe and the United States and established Jenner as the forefather to modern vaccination (Jenner 1799; Allen 2007, 49–50). By the mid-nineteenth century, compulsory vaccination was introduced in select cities in the United States; its inception was closely followed by resistance. Support for vaccination and anti-vaccination sentiments has waxed and waned through periods of epidemics, contaminated vaccines, the rise of the pharmaceutical industry, scientific advancement (including the development of germ theory), government involvement in vaccine regulations, and the recent rapid expansion of vaccination requirements.
for children. A brief historical analysis of the anti-vaccination movement is necessary to understand the roots and motivations of the contemporary iterations of the movement, including the role of schools in vaccination compliance and the rise of vaccination exemptions. For the purposes of this thesis, the contemporary anti-vaccination movement is defined as 1980 to present. There are many similarities between the anti-vaccination movement of the early twentieth century and the current movement (with necessary modernizing adjustments), particularly analogous motives and arguments to oppose compulsory vaccination. This historical review provides the context and background necessary to understand the anti-vaccination movement, school vaccination laws and vaccination exemption policies.

**Vaccination Laws: a historical review**

Throughout the nineteenth century in the United States, massive reforms in public health and public school education changed both the health and education landscapes, paving the way for vaccination requirements for school attendance. Compulsory school attendance laws resulted in the rapid growth of public schools, many of which were overcrowded and unsanitary, creating ideal conditions for the spreading of communicable diseases (Duffy 1978). As cities and towns formed boards of health and health departments, the leaders of these establishments recognized that large numbers of children in close proximity facilitated the spread of diseases including smallpox, leading to the creation of compulsory vaccination for school attendance (Duffy 1978). In general, compulsory laws were first adopted in large population centers and gradually spread to more rural areas. The first recorded vaccination law in the United States was imposed by the city of Boston in 1827 and Massachusetts became the first state to mandate vaccination for school entry in 1855 (Allen 2007, 60; The College of
Physicians of Philadelphia 2015). In 1860, New York became the first state to give power to school districts to exclude unvaccinated children from school. However, this law did not preclude many non-vaccinated children from attending school as enforcement was, at best, sporadic and many school officials openly opposed exclusion claiming that it would empty classrooms (Allen 2007, 60). Following the examples of Massachusetts and New York, multiple New England states adopted compulsory vaccination laws in the late nineteenth century (Duffy 1978). More so than other populous urban centers, Philadelphia struggled with vaccination due to rampant political corruption; despite a smallpox eradication strategy and vaccination requirements for school children starting in 1870, multiple smallpox outbreaks occurred throughout the 1870s and 1880s (Duffy 1978; Allen 2007, 73–74). Pennsylvania did not pass a law excluding unvaccinated students from school until 1895 (Allen 2007, 73–74). Baltimore had vaccination laws by 1881, when the city health department reported inspections of schools for vaccination compliance (Duffy 1978).

In the Midwest, Chicago adopted a compulsory vaccination law in 1868, and Illinois followed in 1882 (Chicago Board of Health 1876, 66–67; Rawlings 1927, 1:148). Indiana, Iowa and Ohio adopted vaccination requirements for schools during epidemics in 1881, 1889 and 1898 respectively (Duffy 1978). Many of these laws were subsequently overturned by 1915, as seen in Figure 2.1.

In the South, Louisiana established a Board of Health with vaccination laws in 1855, but this law was largely unenforced outside of New Orleans until the 1890s. Elsewhere, laws were not passed until after the Civil War and mainly were found in urban centers. In general, southern states lagged behind the northern states in developing public school systems, thus they were slower in compulsory vaccination policies. Virginia and Arkansas passed laws in 1882
requiring vaccinations for all public school students (Duffy 1978). Other Southern states slowly established boards of health and vaccination laws but many were ineffective. For example, Alabama established a state board of health and authorized the creation of county health departments in the 1870s. However, when a smallpox epidemic broke out in 1897 not a single county had a full-time health organization (Willrich 2011, 66). Not surprisingly, racial tension and discrimination over vaccination occurred throughout the South. In pre-Civil War Virginia, most slaveowners vaccinated their slaves when a smallpox threat was present and several cities provided free vaccination to destitute free blacks during epidemics (Savitt 1978, 220–225). After the Civil War, when epidemics broke out, African Americans were usually the first to be subjugated to forced vaccination, sometimes encountering police brutality. In general, Southern African Americans were neglected and mistreated by the predominantly white medical profession and therefore were less likely to seek medical attention, let alone be vaccinated (Willrich 2011, 67, 100–102).

African Americans were also blamed for many of the smallpox epidemics that occurred at the end of the nineteenth century. During the late nineteenth and early twentieth centuries smallpox was believed to be a disease of filth and was frequently associated with the poor and with minorities. In 1899 the United States Surgeon General Walter Wyman issued “Précis Upon the Diagnosis and Treatment of Smallpox” reflecting the current medical knowledge about smallpox that included the misinformation that filth spread smallpox and that smallpox was “more common among the colored races, probably on account of their condition of living in small, crowded rooms, with slight regard for cleanliness” (“Précis Upon the Diagnosis and Treatment of Smallpox” 1899). In reality the link between the poor minorities and smallpox was based on racial and class discrimination, not medical etiology (Willrich 2011, 27).
In 1915 vaccination requirements and regulations varied by state, as visualized in Figure 2.1. 32 states and the territories of Hawaii and Alaska had laws that required vaccination or permitted local jurisdictions to enact vaccinations requirements during specific conditions. Seven states had laws that either prohibited or limited vaccination ranging from Utah’s prohibition of any vaccination requirements at any age to Arizona’s requirement that parental consent was required for compulsory vaccination of minor children. The remaining 11 states did not have any laws regarding vaccination (Hanlon 1960, 551–552).

Figure 2.1. Vaccination Laws in 1915
Data Source: Hanlon 1960, 551-553.

There were many drivers that influenced the presence or absence of vaccination laws. While there are some regional similarities, overall the vaccination laws were heterogeneous and
reflect individual state concerns and policies. In general, the industrialized northeastern states
maintained vaccination laws because they contained large population centers susceptible to
fast-spreading epidemics and were ports of entry for immigrants who were believed to spread
disease. In contrast, in the South, immunization laws were often justified as protection from
diseases carried by poor, migratory workers (Jackson 1969; Willrich 2011, 27).

Figure 2.2. Compulsory Vaccination for School Attendance in 1969
Data Source: Jackson 1969

The laws evolved and changed many times throughout the next 60 years, varying by
state. Initially only smallpox was required but as other vaccines were introduced and adopted --
diphtheria in the 1930s; polio in the late 1950s; and measles, tetanus and pertussis in 1960s --
states updated their vaccination requirements. However, these updates occurred at the
discretion of the states and were not temporally uniform (The College of Physicians of Philadelphia 2015). There were 26 states that had at least one vaccine requirement for school entry in 1969 (Figure 2.2), though twelve states required all six available vaccinations (Jackson 1969). The 26 states were predominately east of the Mississippi River and included the 13 states that had compulsory laws in 1915. The largest policy changes between 1915 and 1969 occurred in California and Minnesota, who changed their policies from prohibiting compulsory vaccination to mandating it, and Missouri and Illinois, who shifted from no vaccination laws to compulsory vaccination laws.

The general trend between 1915 and 1969 was the maintenance of or shift to statewide compulsory vaccination laws. This trend continued into the 1970s due to federal pressure as the CDC and the Department of Health and Human Services pushed to eradicate measles by urging governors to enact and enforce vaccination laws (Allen 2007, 244; Orenstein and Hinman 1999). The CDC started monitoring the vaccination rates of kindergartners in 1978, requesting that states annually assessed and reported both vaccination and exemption levels (Stokley et al. 2011). By 1980, all states had laws requiring vaccination for school attendance, though the number and type of vaccinations required varied (Orenstein and Hinman 1999; Salmon et al. 2006).

Vaccination Exemptions

Since the beginning of compulsory vaccination laws, people have sought exemptions. In 1894 Massachusetts permitted medical exemptions if a child was deemed “unfit for vaccination” by a physician (Duffy 1978). This law only protected those under 21, even though vaccination was mandatory for all ages. In Jacobson v. Massachusetts (1905) the landmark Supreme Court
case supporting compulsory vaccination, the prosecution argued unsuccessfully that the Massachusetts vaccination exemption policy violated the 14th Amendment’s equal protection provisions, yielding legal justification for states to impose vaccination requirements (Colgrove 2006, 38–44; Jacobson v. Massachusetts 1905). Although most states with vaccination laws did not have exemptions, they were sometimes permitted locally. For example, the lack of a New York state exemption law did not stop the New York City health commissioner from exempting the child of a vaccination objector to attend school in 1931 (Colgrove 2006, i).

By 1969, 26 states required vaccination for school entry and almost all of these permitted medical and religious exemptions (Jackson 1969). Medical exemptions are granted for a medical condition that prohibits vaccinations for health reasons whereas religious exemptions are requested when there “is a provision in the [state] statute that allows parents to exempt their children from vaccination if it contradicts their sincere religious beliefs” (National Conference of State Legislatures 2015). Religious exemptions were established in large part due to the successful lobbying efforts of the Christian Science Church (Colgrove 2006, 56–57). Officially established in 1879, the Christian Science Church believes that illness is a mental disorder and that diseases can be avoided by prayer (Eddy 1875). Since its inception, Christian Scientists have been vocal anti-vaccinators and have led multiple attempts to overturn compulsory vaccination laws in the name of religious freedom. In the 1960s, Christian Scientists were one of the most politically powerful religious groups in the United States and their lobbying for religious exemptions passed in New York State in 1966. All other states that required vaccinations quickly followed suit (Offit 2011, 141–142). However, states are not required to allow religious exemptions as established in Prince v. Massachusetts (1944). This case affirms that religious freedom does not extend to actions that endanger others, to include
public health (Prince v. Massachusetts 1944). The third type of exemption is classified as a personal belief exemption (PBE), sometimes referred to as a philosophical exemption. In 1969 five states, Missouri, Rhode Island, Illinois, Michigan and Ohio allowed for PBEs if a parent objected to vaccination in writing (Jackson 1969).

In 1979 Mississippi revoked its religious exemption policy, allowing only for medical exemptions (Diekema 2014). For the 2015-2016 school year Mississippi and West Virginia do not allow for any Nonmedical exemptions (NMEs) (National Conference of State Legislatures 2015). California’s vaccination law changed in 2015 and will not allow NMEs starting in the 2016-2017 school year (Mello, Studdert, and Parmet 2015). All other states offer either religious or personal belief exemptions to those that desire to avoid vaccination. Religious exemptions are included in 45 state statutes (see Figure 2.3). Minnesota and Louisiana do not explicitly recognize religious exemptions; however, they allow religion as a justification for PBEs. PBEs are permitted in 17 states for kindergarten; Missouri only allows PBEs for childcare facilities. Each state has a different definition of a PBE, but in general they include objections to vaccination based on parent(s) beliefs. (National Conference of State Legislatures 2015).
While there are only two types of NMEs, each state creates the policies for obtaining a NME, resulting in heterogeneity in the difficulty for an individual to obtain an exemption. Rota et al. (2001) classified each state, based on the complexity of obtaining a NME as either easy, medium or difficult. A state is considered “easy” if the state only requires the signature of a parent on a school-provided form and no research or special visits are required. The “medium” classification is assigned to states that did not require notarization but required that the form be obtained from the health department or that the parent must provide a letter or statement. The “hard” classification is assigned to states that require at minimum a health department procured form and personal statement or require a notarized form or letter (Rota et al. 2001). A
study discovered that states classified as “easy” had higher rates of NMEs than those classified as “medium” or “difficult” (Omer et al. 2006). Current literature suggests that the difficulty of obtaining an NME can influence the number of NMEs present (Omer et al. 2006; Salmon, Omer, et al. 2005; Blank, Caplan, and Constable 2013). Classifications based on the easy/medium/hard classification for obtaining an NME for the 2015-2016 school year again stresses variation between states (Figure 2.4). The influences behind NME difficulty vary, but could be remnants of historical policies. Of the 13 states that had state-wide compulsory vaccination in 1915, only two are currently considered “easy” states and of the 26 that required vaccination in 1969, only three have the “easy” classification.

Figure 2.4. Difficulty of Obtaining a Vaccination Exemption for the 2016-2017 School Year
Data Sources: Omer et al. 2012; National Conference of State Legislatures 2015; Raja and Mooney 2015
The rates of vaccination exemptions have been rising since the mid-1980s (Feikin et al. 2000). Omer et al. reported that in states with PBEs, exemptions rose from 0.99% in 1991 to 2.54% in 2004 (2006). The introduction of new exemption policies has also contributed to the rising number of NMEs; after Arkansas passed a law allowing PBEs starting in the 2003-2004 school year, the number of overall exemptions increased and clustered geographically: 13% of the state public school NMEs were located in just 10 of the 256 school districts. These high exemption school districts were dispersed throughout Arkansas. The study did not analyze if these high exemption rate school districts were composed of similar geographic or demographic characteristics (Thompson et al. 2007). States with more vaccinations required for school entry have an overall higher vaccination rates when comparing all CDC recommended immunizations. For example, in states that require the varicella (chicken pox) vaccine, the varicella immunization rates are much higher than in states that do not require it for school entry, proving that vaccination laws are an effective tool (Davis and Gaglia 2005). Many recent studies have proven that requiring immunizations for school age children decreases the incidence rate of infectious disease and increases the overall vaccination rates (Orenstein and Hinman 1999; Philip J. Smith, Chu, and Barker 2004; Omer et al. 2006; Atwell et al. 2013).

Anti-Vaccination Movements, 1882-1940

Although individuals have opposed vaccination since the creation of the first mandatory laws in Boston, it wasn’t until the 1870s that formal organizations were formed (Willrich 2011, 254). The New York Anti-Vaccination League was founded in 1882; three years later the board of trustees consisted of 15 members, all of whom were animal rights activists and/or alternative medicine practitioners. The anti-vaccination movement started by attacking vaccinations for
cruelty to animals during experimentation and testing, common in late nineteenth century medicine. This incarnation of the anti-vaccination movement was characterized by the traditional medical community as producers and peddlers of patent medicines and shunned (Allen 2007, 85–86; The College of Physicians of Philadelphia 2015). Despite this, during the next few years other anti-vaccine groups emerged each with their own agenda, including the Brooklyn Compulsory Anti-Vaccination League, New England Anti-Compulsory Vaccination League (Hartford, CT), the Anti-Vaccination Society of America (Indiana) and the Massachusetts Compulsory Anti-Vaccination Association. Many other states and local societies had distinct anti-vaccination organizations, but there was a general lack of coordination and organizational discipline within the movement (Colgrove 2006, 52; Willrich 2011, 254).

Anti-vaccination groups had multitudes of evidence to support their cause because at the turn of the century public health legitimacy was struggling, especially in growing cities. Corruption was rife and the pharmaceutical industry was largely ungoverned. Unregulated vendors frequently sold contaminated vaccines and side effects were common and severe: in the midst of a smallpox epidemic in 1902 smallpox vaccinations in Philadelphia were contaminated with tetanus, killing 11 children (Allen 2007, 80). Furthermore, city departments of health imposed aggressive tactics for those that refused vaccination. One case reported in the New York Times concerned the McCauley family from Brooklyn in March 1894. After they refused vaccination, the police quarantined the McCauleys, placed them under armed guard, and threatened arrest to anyone caught visiting them or delivering them food. The McCauleys escaped, but turned themselves in three days later in Hoboken, NJ and were immediately vaccinated (New York Times 1894, 5; Colgrove 2006, 22; Offit 2011, 133–134). When a smallpox epidemic broke out in Middlesboro, Kentucky in 1898 physicians and police worked together to
enforce a mandatory vaccination order; all who resisted were handcuffed and vaccinated at gunpoint, and African Americans that refused were much more likely to encounter violent force (Willrich 2011, 46, 58).

The anti-vaccination movement gained momentum in 1908 when self-made millionaire John Pitcairn and businessman Charles Higgins consolidated many smaller anti-vaccination groups and provided the capital to form the Anti-Vaccination League of America. Both Pitcairn and Higgins funded many pamphlets and rallies to spread the anti-vaccination cause (Offit 2011, 134). Pitcairn also supported political candidates in multiple failed attempts to overturn compulsory vaccination laws (Allen 2007, 100–103).

Another notable anti-vaccination crusader was Lora C. Little, a mother whose son had died of measles and diphtheria but whose death she attributed to smallpox vaccination. Little was a tireless activist who wrote many pamphlets, led successful campaigns against mandatory vaccination in North Dakota and Minnesota, and was even arrested under the Espionage Act in 1918 for an attempt to convince soldiers to refuse vaccination (Allen 2007, 104–105). In many ways Lora Little was similar to anti-vaccination mothers today: her actions were based on paranoia regarding a state public health agency, she actively encouraged people to be their own doctors, she frequently used emotionally appealing anecdotal evidence in her pamphlets, and she lobbied against government vaccination policies.

Anti-vaccination crusaders attempted to overturn many compulsory vaccination laws resulting in court cases at all levels. The Supreme Court case regarding vaccination that has had the most impact is Jacobson v. Massachusetts (1905), which provides legal basis for states’ jurisdiction over vaccination stating:
The authority of the State to enact this statute is to be referred to what is commonly called the police power — a power which the State did not surrender when becoming a member of the Union under the Constitution... According to settled principles the police power of a State must be held to embrace, at least, such reasonable regulations established directly by legislative enactment as will protect the public health and the public safety (Jacobson v. Massachusetts 1905).

*Jacobson v. Massachusetts* was later invoked as the basis for compulsory vaccination laws and as a prerequisite for school enrollment in *Zucht v. King* (1922). Under states’ legal powers for requiring and enforcing public health regulations, they can mandate vaccinations policies and enforcement for entry into school for children under the age of 18. Both *Jacobson* and *Zucht* have caused lower courts to give “considerable deference to the use of the states’ police power to require immunization to protect the public health” and provide legal basis for vaccination exemptions (Cole and Swendiman 2014).

By the 1930s, the anti-vaccination movement had lost most of its momentum. Scientific discoveries of diphtheria, tetanus and tuberculosis vaccines, combined with the introduction of the sterilized needle provided medicine as a whole legitimacy, which in turn increased public confidence in vaccines (The College of Physicians of Philadelphia 2015). By the beginning of World War II, vaccines were accepted as essential for saving service-members’ lives and necessary for winning the war and anti-vaccination rhetoric had all but disappeared from the American landscape.

**Anti-Vaccination Movement, 1945-present**

Post WWII, the anti-vaccination viewpoint was not popular. The very public race to find a cure for polio and the general love of all things science and technology related throughout the beginning of the Cold War overrode most anti-vaccination sentiment. Many areas of the United
States reported low vaccination rates; however, public health inquiries attributed the rates to apathy rather than active resistance (Allen 2007, 160–163, 298). Most public health officials credit the birth of the current anti-vaccination movement to the airing of the PBS television program *DPT: Vaccine Roulette* on April 19, 1982. However, when *Vaccine Roulette* aired in the United States, the United Kingdom’s anti-vaccination movement had already been fighting against the Diphtheria, Tetanus, Pertussis, (DTP) vaccine for eight years, setting ripe conditions for an anti-vaccination movement within the United States. *Vaccine Roulette* investigated the safety and effectiveness of the pertussis vaccine, highlighting many personal stories of children who suffered from seizures and other injuries after receiving the DTP vaccination (Allen 2007, 251–255; Offit 2011, 2–7). Unlike the earlier anti-vaccination movement, by 1982 there was considerably less negative evidence against pharmaceutical companies and vaccines. Vaccines were licensed and distributed by reputable pharmaceutical companies, but occasionally there were issues with new vaccines. In the early 1970s, a measles vaccine produced by Lilly and Pfizer did not provide measles immunity in over 1 million children; instead as many as 160,000 developed atypical measles. While only one death was reported from this incidence, Lilly and Pfizer withdrew from the human vaccine business (Nichols 1979; Allen 2007, 231–232).

Government oversight on vaccination production was not perfect, but monitoring and regulations were better than they had ever been previously. *Vaccine Roulette* brought forth many allegations including that the DTP vaccine caused “learning disabilities” and Sudden Infant Death Syndrome (SIDS), that pertussis was not a serious disease and that the development of antibiotics made the chance of death from pertussis rare. In addition, *Vaccine Roulette* made many generalizing statements about the seriousness of vaccine reactions and that doctors were unaware of the risks of the DTP vaccine.
In a congressional hearing that investigated allegations brought forth from *Vaccine Roulette*, the American Association of Pediatrics (AAP) referred to the program as “imbalanced”, “biased” and “inaccurate” and refuted many of the allegations in detail. These included referencing peer-reviewed studies that disproved the link between DTP and SIDS, emphasizing the rarity of DTP vaccine reactions and citing statistics on the dangers of pertussis including death rate – around one percent for children and higher in infants under six months of age (Committee on Labor and Human Resources 1982, 111–115).

*Vaccine Roulette* provided the impetus for a few parents of vaccine-affected children to join together and form DPT: Dissatisfied Parents Together. Founded in Fairfax, Virginia in 1982, Dissatisfied Parents Together was the first modern anti-vaccination advocacy group. The name was eventually changed to the National Vaccine Information Center (NVIC) and is the leading anti-vaccination group in the United States (Allen 2007, 254; Offit 2011, 2–7; “National Vaccine Information Center” 2015). The NVIC’s mission statement is:

> The National Vaccine Information Center is dedicated to the prevention of vaccine injuries and deaths through public education and to defending the informed consent ethic in medicine. As an independent clearinghouse for information on diseases and vaccines, NVIC does not advocate for or against the use of vaccines: We support the availability of all preventive health care options, including vaccines, and the right of consumers to make educated, voluntary health care choices” (“National Vaccine Information Center” 2015).

From the beginning, the group has had a large political influence; the cofounders, Barbara Loe Fisher and Kathi Williams, testified at the very first committee hearings on vaccine safety, worked with Congress on the National Childhood Vaccine Injury Law of 1986, and successfully lobbied for the creation of the Vaccine Adverse Events Reporting System (VAERS), a database that records all adverse reactions reported after receiving a vaccine (Committee on Labor and Human Resources 1982; “National Vaccine Information Center” 2015). Today, the NVIC is a
strong nonprofit organization that provides resources to educate people about vaccine safety, encourages parents to become advocacy team members that work locally in supporting state vaccine exemption laws and has a large media presence both online and in print. In addition to outreach programs, the NVIC has testified numerous times to Congress against specific vaccines, most recently in 2012 against the Hepatitis B vaccine (“National Vaccine Information Center” 2015).

**Similarities between Anti-Vaccination Movements**

The similarities between anti-vaccination movements emphasize that the current anti-vaccination movement is not new, using many of the tactics and arguments that are over 100 years old. Some are tactical (using mass media and public rallies to spread information, and using legal systems to extract vaccine injury compensation); some are product-based (promoting alternative medicines rather than vaccines), and some are emotionally or culturally driven (views that vaccines are unnecessary and unnatural). In one instance the contemporary movement directly copied a past tactic: in 1895 The Anti-Vaccination Society proposed a controlled experiment to boards of health in which 5,000 children would be vaccinated and 5,000 unvaccinated to establish vaccination effectiveness and side effects. This same experiment was suggested by NVIC president and noted anti-vaccination activist Barbara Loe Fisher in 2005 as a way to ascertain the side effects of vaccination. Neither experiment was ever conducted (Allen 2007, 86).

Historical anti-vaccinators such as Lora Little were prolific in producing pamphlets, bulletins and books to spread their message and using charismatic leaders to appeal to the American public (Allen 2007, 105). *Ladies Home Journal* ran pro- and anti-vaccination essays in
“The Fallacy of Vaccination” was authored by notable anti-vaccinationist John Pitcairn (Schamberg 1910; Pitcairn 1910). *Ladies Home Journal* had widespread influence in America; in 1903 it was estimated that 20 percent of the population read it (Roth 1991). Fitness guru Bernarr Macfadden, who built a media empire in the 1920s, published numerous tabloid magazines, including *Physical Culture* and *New York Evening Graphic*, both of which contained articles opposing vaccination. The nationwide circulation of Macfadden’s publications was estimated at forty million people (Colgrove 2006, 57–58). Today’s media platforms have evolved to include the internet and television, but the passion of contemporary anti-vaccinators to publish their message is similar to the historical fervor. The television show *The Dr. Oz Show* started as a popular segment on Oprah and has reached massive audiences. On his show, Dr. Oz has dispensed anti-vaccination information, encouraging parents to avoid the recommended annual influenza vaccine and promoting alternative vaccine schedules that directly contradict the CDC recommended schedule. In addition Dr. Oz has co-authored a book that contains information on alternative vaccine schedules for parents (Offit 2011; “The Dr. Oz Show” 2015, 188–190). Oprah Winfrey has hosted multiple anti-vaccination leaning celebrities on her television show including Jenny McCarthy and Holly Robinson Peete. Former Playboy model and TV personality Jenny McCarthy, whose son has autism, has written multiple books on anti-vaccination and alternative autism therapy books which she has promoted on the Oprah Winfrey Show and on Oprah’s website (Largent 2012, 146–147; Winfrey 2007; Offit 2011, 150). The internet has a plethora of vaccination and anti-vaccination platforms – searching the internet today for vaccination information will most likely include NVIC in one of the top search results, as well as numerous books, parent forums and blogs containing conflicting information and guidance regarding vaccines. The NVIC homepage encourages parents to “know the risks
for your child” and contains alternative vaccination schedules, current and proposed state vaccination policies, information on how to obtain an exemption in your state and potential side effects of vaccines including resources on autism ("National Vaccine Information Center" 2015).

Historically, public rallies were frequently used to generate support for the anti-vaccination cause, although most were unsuccessful at altering public policy. The anti-vaccination movement held multiple rallies and demonstrations including in 1906 the withdrawal of 4,000 students from school in Erie, Pennsylvania in protest of vaccination requirements. In 1926 an armed mob drove health officers from Georgetown, Delaware, thus successfully preventing a forced vaccination attempt (Allen 2007, 111; The College of Physicians of Philadelphia 2015). The use of rallies and protests are also common in the anti-vaccination community today. In 2008, celebrities Jim Carrey and Jenny McCarthy led a “Green our Vaccines” rally in Washington D.C. to protest against vaccine ingredients (Offit 2011, 116–117). In California, multiple local protests occurred throughout the spring of 2015 as the state legislature debated removing religious and personal belief exemptions as an avenue to avoid vaccination for school age children (Jamison 2015; Luke 2015; CBS Sacramento 2015). While these rallies have been unsuccessful in overturning policy, the publicity generated draws attention to their cause, attracting additional supporters.

Another similarity between the historical and contemporary anti-vaccination movement is the role of alternative medicine. During the late nineteenth/early twentieth century there were many self-taught healers, homeopaths and alternative medical practitioners that peddled alternative therapies and medicines. These individuals made many arguments against vaccination, including arguing that vaccination was unsanitary, ineffective, and weakened the immune system (Allen 2007, chap. 3). One form of alternative medicine, chiropractic, was
founded in 1895 by a magnetic healer in Iowa. The founding tenets of chiropractors included the belief that 95% of illnesses were a result of pinched nerve roots and that a contagious disease such as smallpox could be cured by realignment of the spine. As such, to early chiropractors, vaccines were unnecessary poison being introduced to the body and could be harmful (Campbell, Busse, and Injeyan 2000). Even today, the official policy of the International Chiropractic Association acknowledges the risk of vaccines and questions the wisdom of mass vaccination programs (“International Chiropractors Association” 2015). In addition to chiropractic medicine, there are many alternative views on vaccination including the popular vaccination delay schedule produced by California pediatrician Dr. Bob Sears. This schedule encourages parents to space out vaccination to allow children’s immune systems to handle each disease separately, directly contradicting the guidelines of the CDC and the AAP (Sears 2007). While researching a measles outbreak in San Diego, Sugerman et al. found that parents of unvaccinated children believe that a “natural lifestyle” protects children from vaccine-preventable diseases and that vaccinations are not necessary (2010).

The view that vaccines cause unnecessary harm is threaded throughout the historical and contemporary anti-vaccination rhetoric. While there were many issues with vaccine safety around the turn of the century, in general, vaccines protected people more than the harm caused by vaccination. In 1903 vocal anti-vaccinationist J.W. Hodge regarded vaccination as government-sponsored blood poisoning (Willrich 2011, 259). Lora Little published the book _Crimes of the Cowpox Ring_ in which she highlighted 336 “victims” of vaccinations including those who died of anemia, blindness, blood poisoning, cancer, diphtheria, meningitis and tuberculosis after being vaccinated (Willrich 2011, 268). In 1916, some New York City residents claimed that the smallpox vaccine caused diphtheria and polio; the smallpox vaccine is medically incapable of
causing diphtheria or polio as these diseases are caused by bacteria not present in the vaccine (Offit 2011, 115). Some current anti-vaccination claims are also proven to be medically impossible including that the HiB vaccine causes diabetes and asthma and that the hepatitis B vaccine causes multiple sclerosis (Offit 2011, 61–67). Most famously is the connection between the MMR vaccine and autism, which was published by Andrew Wakefield in 1998. Wakefield’s study and has since been retracted, denounced, and disproven by the medical community (Allen 2007, 387–388; Offit 2011, 93–97), but many anti-vaccination advocates conveniently ignore this and do not accept that the side-effect rate of vaccines is very small.

Another similarity between the historical and contemporary movements is the use of legal systems for vaccine injury compensation. Prior to the twentieth century, personal injury lawsuits were very rare. The rise in harsh quarantine tactics and aggressive vaccination policies in New York City led to an increase in lawsuits involving smallpox vaccination, including three vaccination-related injury and wrongful death lawsuits that occurred in New York City in 1896. The most publicized wrongful death lawsuit was against a vaccinator involving the death of a 10 year old girl, Julia Burggraff, who died of tetanus three weeks following smallpox vaccination (New York Times 1896a; New York Times 1896b). In an era where medical malpractice suits were extremely rare, to have three lawsuits filed within a year was a substantial matter; the next reported vaccination wrongful death lawsuit in New York City was filed two years later in 1898 (New York Times 1898). These lawsuits were settled out of court and did not have a large impact on the pharmaceutical industry.

At the birth of the contemporary anti-vaccination era in 1981, three lawsuits were filed against vaccine makers for DTP-related injuries. Numbers rose sharply with 255 lawsuits filed just five years later in 1986 (Hinman 1988). As the number of lawsuits increased so did the
amount of money requested by plaintiffs: in 1985 the average compensation request was $26 million (Hinman 1988; Hinman 1986; Allen 2007). In general, most lawsuits were settled in favor of the plaintiff; these cases were often won through the power of anecdote and the jury’s acceptance of correlation instead of causation. The increase in such lawsuits increased the cost of vaccines to the individual consumer and forced many vaccine producers to cease production (Allen 2007, 261; Offit 2011, 18–21). For example, in the 1980s the number of companies making the measles vaccine dropped from six to one (Offit 2011, 21). The abrupt reduction in vaccine supplies caused a vaccine shortage that threatened the United States vaccination rates forcing federal involvement. To ensure the supply of vaccines, Congress, with input from the NVIC, passed the National Childhood Vaccine Injury Law in October 1986, protecting vaccine makers from lawsuits and providing an avenue for citizens to be compensated for vaccine damages without having to utilize the state court system (Public Law 99-660 1986; M. H. Smith 1988).

Dr. Jay Frank Schamberg, an infectious disease specialist, wrote a pro-vaccination essay in *Ladies Home Journal* in 1910 that could easily have been penned in response to the contemporary anti-vaccination movement stating “The opponents of vaccine...are on a constant search for ammunition against vaccination. They accept as true every alleged accident after vaccination as resulting therefrom, but assiduously shut their eyes to the evidence offered to the efficacy of vaccination...”(Schamberg 1910, 44). Anti-vaccination sentiment in the United States has existed since the introduction of compulsory vaccination laws. Despite improved regulations, safety and technology of vaccines today, the anti-vaccination movement has continued into the twenty first century. Whether tactical, product-based or culturally driven, the current anti-vaccination movement echoes many arguments of the Progressive Era.
Current Anti-Vaccination Risk Factors

There are many inter-related dynamics that influence a parent’s decision to vaccinate their child. Among the biggest are vaccination and exemption laws, time constraints, priorities, social pressure, perception of risk and vaccination safety information/misinformation (Gust et al. 2004; P. J. Smith et al. 2006; Senier 2008; Brunson 2013; Blank, Caplan, and Constable 2013). Price is likely not a major factor into a parent’s decision-making process because insurance covers immunizations and children without insurance are covered under the Vaccines for Children (VFC) program. Established in 1994, VFC authorizes the federal government to provide immunizations at no cost to qualifying children including children without insurance and those covered by Medicaid (Conis 2015, 161–177; CDC 2014b). While the choice to vaccinate is an individual one, at a larger scale researchers have unearthed trends and risk factors of those most and least likely to vaccinate.

In the past 20 years, research by medical geographers, sociologists, epidemiologists and others have studied undervaccinated and unvaccinated children in the United States attempting to discover trends and risk factors of parents who are most likely to not vaccinate. Multiple studies have found that socioeconomic factors like low income and low educational attainment, vaccination history and demographics put certain populations at higher risk for undervaccination or vaccination delay, defined as not receiving vaccinations in accordance with the recommended CDC schedule (Daniels et al. 2001; Dombkowski, Lantz, and Freed 2004; Gust et al. 2004; Luman et al. 2005). In the past, low-income, urban children are at highest undervaccination risk. In the early 1990s, children in low-income urban areas were significantly more likely to be undervaccinated than suburban counterparts (Williams et al. 1995). In a study focusing on inner-city subsidized day care facilities, researchers found only 44.2% of the children
were up to date (UTD) at one year of age despite state regulations mandating vaccinations for all children in child care facilities. This same study found large differences between the overall city infant vaccination rate compared to subsidized child care rate, indicating that poor, inner-city children were much more likely to be underimmunized than their non-poor, suburban counterparts (McCaskill et al. 2008). While low income and poverty have served as barriers to vaccination on the past, a study in 2009 discovered that the gap is narrowing (Philip J. Smith et al. 2009). Although disparities may be decreasing, the 2013 annual vaccination coverage report by the CDC recognized that children living below the federal poverty level had the lowest vaccination coverage of children aged 19-35 months (Elam-Evans et al. 2014). In addition, minority children are at greater underimmunization risk compared to white children (Daniels et al. 2001; Chu, Barker, and Smith 2004; Luman et al. 2005), except in a study of a 2006 birth cohort data which discovered that children of Hispanic ethnicity generally had higher immunization rates than other races (Kattan et al 2014).

Literature that examines school-age immunization rates and NMEs unearths very different attributes and socioeconomic factors than the risk factors previously mentioned. A potential explanation is that school entry requirements force many parents who may not have previously made vaccination a priority to get their children vaccinated in order to meet requirements. In fact, for some undervaccinated children, school entry requirements serve as a “safety net” catching children who have fallen behind on requirements (Orenstein and Hinman 1999; Jiles, Fuchs, and Klevens 2000). Research shows that state policies can influence vaccination rates; in one study, 11.7% of parents of undervaccinated children and 6.3% of parents of vaccinated children reported that their child received a vaccine that they were against because it was required for school entry (Gust et al. 2004). Additionally, many
Undervaccination risk factor studies are conducted using National Immunization Survey (NIS) data, which provides state and federal level data but does not ask for a reason behind undervaccination. The lack of local-scale data is one of the biggest critiques of NIS data (Salmon 2006; Philip J. Smith et al. 2009; Zhao and Luman 2010; Kattan et al. 2014).

If a parent obtains an NME they are actively choosing to avoid immunizations for their child. A study on exempt children in Southern California indicated geographic clustering with socioeconomic indicators including high educational attainment, higher household income, lower average family size and low population density (Atwell et al. 2013). These clusters were also associated with high rates of pertussis incidence, an indicator that the community studied was below the herd immunity threshold. Exempt children were more likely to have parents older than 35 with at least some college (Salmon, Moulton, et al. 2005). Mothers of exempt children were also more likely to have a college degree and to be non-Hispanic white (Gust et al. 2004). In San Diego, another study found that high exemption levels in public, charter and private schools correlated to white, college-educated, high income parents living in areas with generally high socioeconomic indicators (Sugerman et al. 2010). In 2001, a study found that private school students had higher exemption rates than the state average (Salmon, Omer, et al. 2005).

Parents that choose vaccination exemptions for their children tend to have similar ideas on vaccine efficacy, vaccine safety and the dangers of vaccine-preventable diseases (Salmon, Moulton, et al. 2005; Omer et al. 2009; Sugerman et al. 2010)). In addition, misinformation played a major factor in parents’ decisions, as many believe that vaccines can cause autism and other health conditions (Sugerman et al. 2010). Rationales for refusing vaccines commonly list concerns about vaccine safety and a low level of concern about the risk posed by vaccine-
preventable diseases (Omer et al. 2009). Parents of exempt children were more likely than parents of vaccinated children to report a low level of trust in the government, low perceived susceptibility to and severity of vaccine-preventable diseases, and low perceived vaccine safety and efficacy. They were also less likely to report confidence in medical, public health and government sources for vaccine information and more likely to report confidence in alternative medicine (Salmon, Moulton, et al. 2005). Furthermore, parents of unvaccinated children stated that doctors were not influential in making their vaccination decisions (Philip J. Smith, Chu, and Barker 2004).

The literature reviewed in this section focuses on who is least and most likely to vaccinate their children. Understanding who is most at-risk for undervaccination is important; it is equally critical to be able to identify where undervaccinated populations are concentrated. To identify these locations geolocated vaccination data is needed at the local scale. The CDC identifies the need to study vaccination data, yet they have a limited capability to do this for kindergartners at the state-level and cannot study lower scales (Seither et al. 2013; Seither et al. 2014; Seither et al. 2015). Vaccination data needs to be analyzed at the local scale – patterns and trends are lost when reported at the state-level. In 2015 only 10 states published the smallest scale vaccination and exemption data publicly available, the school-level.

Most literature on vaccination NMEs below the state level is centered on California (Omer et al. 2008; Sugerman et al. 2010; Atwell et al. 2013; Lieu et al. 2015). California may be a hot spot of NME research due to the large amount of publicly available data, a substantial, diverse population, the reputation of alternative medicine within California, the vocal anti-vaccination groups including celebrities and the multiple pertussis epidemics that have occurred within the state. Besides the plethora of literature already available on California, the recent
policy change gives credence to studying a different state. In 2015 the vaccination laws in California were changed, phasing in the removal of NMEs starting in the 2016-2017 school year (Mello, Studdert, and Parmet 2015). This law has large impacts on the long term benefits of research being currently conducted on California vaccination exemption spatial trends as it will soon be out of date.

Instead of studying California, the remainder of this thesis focuses on vaccination and NME patterns and trends in Illinois. Similar to California, Illinois has diverse, rich vaccination data for a large heterogeneous population. Illinois also had a measles outbreak in 2015 not connected to the Disneyland measles outbreak that included 15 people infected from January to April 2015 (Clemmons et al. 2015). However, unlike California, minimal research has been conducted on Illinois vaccination patterns and NME locations.

Why Illinois?

Illinois is the fifth most populous state in the United States with varying population density, racial composition and income levels from the large urban core, suburbs and exurbs of Chicago to the rural farmlands that characterize a considerable portion of the counties to the west and south. The 2010 census recorded the population of Illinois as 12.8 million. Chicago is the largest city in the state with a population of 2.6 million and there are seven other cities with populations over 100,000 (United States Census Bureau 2015a). There are also many rural areas with low population density in the central and southern portion of the state. The population density and distribution of school-age children are depicted in Figures 2.5. and 2.6.

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9 The 8 largest cities in descending order are: Chicago, Aurora, Rockford, Joliet, Naperville, Springfield, Peoria and Elgin.
Figure 2.5. Total Population of Illinois by County
Source: United States Census Bureau 2016b

Figure 2.6. Population of Illinois School-Age Children by County
Data Source: United States Census Bureau 2016c
The K-12 education system in Illinois is as diverse as the population, with multiple small school districts composed of one school with 10 or fewer students to the City of Chicago Public School District with 758 schools and 373,910 students (2013-2014 school year). In 2013-2014 the Illinois K-12 system encompassed 969 public school districts and 336 private school districts (Illinois State Board of Education 2015a). Illinois reported 5,035 schools for the 2013-2014 school year and compiled vaccination data at the school level on 4,884 of these schools (Illinois State Board of Education 2014).

An advantage to studying Illinois is that demographically is one of the best representations of the United States. In 2007 the Associated Press rated Illinois as the most average state based on demographic census data (Ohlemacher 2007). Also based on census demographic data, Business Insider rated Illinois as the most representative state, calling it a “microcosm of America” (Kiersz 2014).

Illinois maintains detailed vaccination records including exemptions by vaccine at the school-level, making it an ideal state to study vaccination exemption patterns over time. This data is publicly available on the Illinois State Board of Education (ISBE) website (Illinois State Board of Education 2015e). Not all states maintain records of vaccinations or vaccination exemptions at the school-level and even fewer make them publicly available. In fact, many states go through great lengths to hide vaccination data from the public; when approached by a journalist to inquire about vaccination records Hawaii’s Department of Health stated that it does not make data available because residents might get angry at schools. For the same situation, a representative from the state of Maine stated that they destroy the vaccination data as soon as they report it to the CDC (Hoyer 2015). Some states do not collect vaccination data annually –

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10 Reference Footnote 7 for list of states that published school-level vaccination data in 2015.
for the 2013-2014 school year Wyoming did not report any vaccination or exemption data to the CDC (Seither et al. 2014). The availability and thoroughness of Illinois vaccination data for a ten-year time period makes it ideal for studying spatial patterns and trends.

**History of Vaccination Policy in Illinois**

Chicago has led public health initiatives within the state of Illinois since the city’s infancy. The city was incorporated in 1837, four years after the first sanitary ordinance was passed. In 1837 a health officer and a board of health was appointed but was defunct for a number of years, went out of existence in 1857 and was abolished in 1860 (Rawlings 1927, 1:102–105). In 1867 during the middle of a smallpox epidemic that killed 123 people out of the approximately 224,000 residents Chicago established the predecessor to the city’s current board of health (Rawlings 1927, 1:50). This Chicago Board of Health was modelled after the New York Metropolitan Board of Health (established 1866) and included a sanitary superintendent, whose duties included smallpox vaccination (Rawlings 1927, 1:105). Upon his appointment, the sanitary superintendent Dr. J.H Rauch hired health inspectors to inspect schools for evidence of vaccination which included vaccination scars and certificates of vaccination. In their reports, these inspectors reported a high level of vaccination inspection opposition and recommended compulsory vaccination laws. The law was approved by the Chicago City Council in 1868 and the formation of a special group of enforcement officials resulted in a dramatic increase in the percentage of schoolchildren vaccinated and decrease in the number of smallpox cases in school age children within Chicago – out of 227,113 pupils enrolled in Chicago Public Schools from 1867 to 1881 only 15 smallpox cases developed, even though multiple outbreaks occurred throughout the city (Chicago Board of Health 1876, 66–67; Duffy 1978).
Following the lead of Chicago, the Illinois State Board of Health was created in 1877 and enacted mandatory vaccination laws in 1882 after a two-year state-wide smallpox outbreak killed an estimated 2,500 people (Rawlings 1927, 1:50, 148; Hodge and Gostin 2001; Illinois State Bar Association 1935, 1752). However, this law was short-lived – in November 1895 the Illinois Supreme Court ruled that the board of health could only enforce school vaccination during outbreaks or when smallpox threatened communities (Rawlings 1927, 1:156–157). This ruling was upheld in *Potts v. Breen* in 1897 and *Lawbaugh v. Board of Education* in 1899 eliminating compulsory school vaccination laws in Illinois for over 70 years (Hodge and Gostin 2001; Green 1904, 2:1864). While other vaccination laws were passed — in 1942 certain nurses working in hospitals were required to be vaccinated against diphtheria — it wasn’t until 1967 that Illinois approved a new law requiring six vaccinations to attend school (Fowler 1942; Jackson 1969; Illinois 75th General Assembly 1967). Since 1967 Illinois has continuously required vaccinations for school attendance, updating specific vaccinations and dosage requirements in accordance with CDC guidelines.

Vaccination policies are mandated by the Illinois School Code Section 27-8.1 [105 ILCS 5/27-8.1] which states that all children must comply with Illinois Department of Public Health (IDPH) required vaccines. Parents are required to submit proof of vaccination or a medical or religious exemption for children entering school for the first time (including out-of-state transfer students) or in kindergarten, fifth and ninth grades. Public and private schools are required to report vaccination compliance of all children to the Illinois State Board of Education (ISBE) by October 15 (105 ILCS 5 2015).

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11 Smallpox, measles, polio, diphtheria, pertussis, and tetanus
12 Vaccines requirements for entry into kindergarten are measles, polio, diphtheria, pertussis, tetanus, mumps, rubella, hepatitis B and varicella (105 ILCS 5 2015; Illinois General Assembly 2014).
Vaccination Exemptions

Since the introduction of compulsory school laws in 1967 the Illinois School Code has allowed for exemptions. The original statute states, “Pupils objection to physical examinations or immunization on constitutional grounds shall not be required to submit themselves thereto if they present to the school board or Teachers College Board a statement of such objection signed by a parent or guardian of the child” (Illinois 75th General Assembly 1967, 3392). While constitutional grounds include any objections based on constitutional rights, vaccination exemptions at this time most frequently involved only religious freedom (Hodge and Gostin 2001).

In 1979 Illinois amended the exemption procedures narrowing exemptions from constitutional grounds to only permitting religious grounds. Parents seeking a religious exemption were required to submit a signed objection statement to the “appropriate local school authority” (Illinois 81st General Assembly 1979, 1033). Religious exemption requirements remained constant until 2015; starting on October 16, 2015, Illinois requires all parents requesting a vaccination exemption to fill out a form with a statement of religious belief for each vaccination exemption requested signed by a health care provider. On top of adding another step in the exemption process, the code specifically addresses philosophical exemptions stating:

The religious objection stated need not be directed by the tenets of an established religious organization. However, general philosophical or moral reluctance to allow physical examinations, eye examinations, immunizations, vision and hearing screenings, or dental examinations does not provide a sufficient basis for an exception to statutory requirements. (Illinois Public Act 099-0249 2015; Illinois 99th General Assembly 2015, para. 8).
This specificity may have been added due to the increased media attention on philosophical exemptions in the past few years including the 2014-2015 measles outbreak in California that placed special emphasis on the role of NMEs. The potential implications of the 2015 change in Illinois vaccination exemption policy will be discussed in future work.

The consistency in vaccination exemption law between 2003-2004 and 2013-2014 vaccination data lends itself to a temporal analysis – since the difficulty did not change, it cannot factor in as a variable as it must in many other exemption studies (Safi et al. 2012; Thompson et al. 2007; Salmon, Omer, et al. 2005). Using the exemption difficulty classification discussed in Chapter 2, Illinois was classified as “medium” difficulty state during this time period. One of the benefits of comparing medium or high difficulty level states is that parents who procure an NME for their child have to commit time and energy into the process, thereby demonstrating dedication to NMEs and not vaccinating their child. If a state has an easy NME process, it is sometimes easier to sign the exemption form than to fill out the vaccination record, leading to complications in determining if the parent is truly committed against vaccinating their child (Omer et al. 2006; Birnbaum et al. 2013; Bradford and Mandich 2015). Since it is not convenient to procure an NME in Illinois, it can be assumed that a parent who seeks an NME is against vaccinating their child. Interviews with parents of NME children in a “medium” difficulty state support this assumption (Sugerman et al. 2010; Rota et al. 2001).

Data Introduction

Annually, the ISBE consolidates and produces the immunization school survey results containing vaccination compliance, medical exemptions and NMEs by vaccine at the school level. This data, collected through an online system, is compiled from the information reported
by school officials (Illinois State Board of Education 2014). ISBE shares this data on their website for all consecutive school years starting with 2003-2004 downloadable in Excel spreadsheets. ISBE assigns a unique identifying code to each education facility within the state. This Region County District Type School (RCDTS) code can change between different school years; ISBE maintains a historical record of RCDTS codes beginning with 2003-2004 school year on their website (Illinois State Board of Education 2015b). This record includes a mailing address for each RCDTS code.

Also available on their website, ISBE publishes a report summarizing immunization status for K-12 schools by school year. These reports begin with the 1998-1999 school year and include all school years through 2013-2014 except for 2003-2004 and 2004-2005. The 2003-2004 report was requested from ISBE through a Freedom of Information Act (FOIA) request; a response was received stating that the 2003-2004 report was destroyed and no longer exists (Vanover 2015; Illinois State Board of Education 2015c). Although the summarizing report is no longer available, the 2003-2004 school-level vaccination data is. The 2013-2014 report contains information on the data collection process, limitations, results and trends and is referenced throughout this thesis (Illinois State Board of Education 2015a).

This thesis examines vaccination and exemption data for two school-years, 2003-2004 and 2013-2014, and includes the following totals listed in Table 2.1.

<table>
<thead>
<tr>
<th>School Year</th>
<th>Total Schools</th>
<th>Geolocatable Schools</th>
<th>Unidentified Schools</th>
<th>Total Students</th>
<th>Geolocatable Students</th>
<th>Unidentified Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-2014</td>
<td>4,884</td>
<td>4,881</td>
<td>3</td>
<td>2,263,883</td>
<td>2,263,514</td>
<td>369</td>
</tr>
</tbody>
</table>
During the study time period, multiple schools closed or consolidated especially in rural areas and schools with low enrollment. Details on school closings are outside the scope of this thesis; however there is a website dedicated to closed, consolidated, deactivated and defunct schools ("Illinois High School Glory Days" 2015). The decrease in school-age children is comparable to demographic shifts within Illinois: the 2000 census reported 2,728,957 children between 5 and 19 years old and the 2010 census reported 2,660,945 children in the same age bracket (United States Census Bureau 2000; United States Census Bureau 2010).

The availability of Illinois’ vaccination and exemption data create the opportunity to conduct a spatial and temporal analysis. The next chapter will address the methods and limitations of this thesis including the data cleaning and school geolocating process.
Chapter 3

Exploring Illinois Nonmedical Vaccination Exemptions: Spatial Analytical Methods

Introduction

This chapter focusses on how the spatial analysis of this thesis was conducted starting with the multi-scalar nature of vaccination policies, the challenges at each scale of analysis and some uniquely geographic research challenges, the Modifiable Areal Unit Problem and edge effects. Next, details on data procurement, cleaning and geocoding are discussed. The limitations section covers limits to the data and the potential impacts they can have on results. Finally, this chapter concludes with the spatial analytical methods, specifically the statistical tests and tools used to answer the aforementioned research questions.

Scale

Vaccination in the United States is fundamentally multi-scalar: the federal-level provides recommendations, the states construct laws, and the local-level enforces laws and collects individual-level vaccination data. This thesis uses state-level data to conduct both state and local-level research. Since state policies derive from federal guidelines, this section contains an overview of federal, state and local-scales.

Annually, the Advisory Committee on Immunization Practices (ACIP), a CDC committee under the aegis of the federal government, provides guidance to the director to the CDC on the
recommended vaccinations for the population at all ages, which is then published as official federal vaccination recommendations. To monitor state and federal vaccination coverage, the CDC collects annual kindergarten immunization and exemption data from each state. With a goal of streamlining data collection, the CDC created minimum standards for assessing vaccination. However, the CDC cannot enforce these standards because there is no official requirement; each state determines their own collection and reporting methods for vaccination data. Only 13 (unspecified) states met the CDC minimum standard for the 2014-2015 school year (Seither et al. 2015; Department of Health and Human Services 2015b). Although the CDC publishes an annual report with this immunization data, trends and comparisons are difficult to assess because of the variety of data collection measures (Seither et al. 2015; Seither et al. 2014; Seither et al. 2013). The lack of an ability to implement policy or collect uniform data at the federal-level creates a heterogeneous landscape of vaccination policies and practices.

State-level study of vaccination data is necessary to determine effectiveness of state policies and to monitor overall vaccination levels. It is also beneficial to the state health department to track vaccination rates in case of an outbreak. If there is a vaccine-preventable disease outbreak, state and local health departments have the responsibility of controlling it. Controlling an outbreak is both resource intensive and expensive. As one example, in 2011, 13 people in Utah developed measles, costing the state more than $330,000 (Hill et al. 2013).

In Illinois, school districts that do not comply with requirements are penalized: any school that reports less than 90% compliance with all health requirements (including vaccination) does not receive 10% of each state-aid payment until reaching compliance levels (Illinois 81st General Assembly 1979; Illinois Public Act 099-0249 2015). In addition, analysis at the state-level can provide insight on temporal trends. For example, the Illinois 2013-2014
school year report shows a rise in religious exemptions from 0.3% to 0.6% from the 2009-2010 school year to the 2013-2014 school year, which equates to an increase of approximately 7,300 additional students with religious exemptions (Illinois State Board of Education 2014; Illinois State Board of Education 2010). However, examination at the state-level may hide local-scale patterns and trends.

The study of vaccination at the local-scale can identify higher risk areas. Schools with a population below herd immunity or with a large pool of susceptible children put students at increased risk of acquiring a vaccine-preventable disease and spreading it to others (Feikin et al. 2000). Previous research has linked religious institutions to disease outbreaks caused by low vaccination levels, showing that local-scale analysis of institutions can provide valuable insight in the event of an outbreak (Sutter et al. 1991; CDC 1994; Kennedy and Gust 2008). Other research identified differences in vaccination rates in different neighborhoods and communities and stressed the importance of local-level studies (Ehresmann et al. 1998; May and Silverman 2003; Omer et al. 2008 and others).

Studying vaccination at the school-level is beneficial because schools are places where populations, otherwise geographically dispersed, converge. They are points of forced interaction where herd immunity is important because disease can spread quickly through a school with low vaccination rates. Examples of recent school school-based pertussis and measles outbreaks are described in Sugerman et al. 2010 and Omer et al. 2008. If vaccination levels are below herd immunity in a specific neighborhood or city block, the risk of an outbreak may not be as high as at a school with low vaccination rates; though the people are geographically proximate they are more isolated than in a school setting.
The rationale for school locations are outside the scope of this thesis; they could be based on historical factors, local ordinances, site availability, political reasoning, proximity to a specific population center or religious center, or any combination of these factors and others besides. Similarly, student populations vary greatly in numbers and the geographical catchment area for students can differ in size and overlap with other schools. For example, Alexander Graham Bell School, a K-8 school in the North Center Chicago neighborhood has a catchment area of less than one square mile for 1,005 students for the 2014-2015 school year (Chicago Public School District 2015a). By contrast, Patoka Elementary School in Patoka, IL has a catchment area of over 10 miles for 174 students for the 2013-2014 school year (“Patoka Community School District” 2015).

One of the challenges of working with geographic data is the Modifiable Areal Unit Problem (MAUP). The MAUP occurs when point data is used to represent areal data, thus masking possible variation inside the areal unit. It is a fundamentally geographic problem because results are always affected by the areal unit selected (Openshaw and Taylor 1979). For this research, individuals are aggregated into schools. Due to privacy and HIPAA concerns, there is no data on specific individuals or their residences. The student population of each school is determined by a myriad of factors. Public schools assign students based on administrative boundaries or local zoning ordinances. Busing and transportation networks may also play a role. Some charter and magnet schools require students to apply and are composed of students from a wider geographic area. Private school student populations are based on parental preference and may contain a select population or demographic. An extreme example of demographic self-selection can be found in the 353 students at the Chicago Waldorf School in Chicago. For 2014-
2015 school year, students in grades 1-12 paid over $17,000 a year each for tuition, excluding all but those of high socioeconomic status (Chicago Waldorf School 2015).

To alleviate MAUP concerns, the analysis will be conducted using the percentage of students with religious exemptions instead of the number of total students. Using population percentage in lieu of total population is common for vaccination data because it is the proportion of vaccinated students versus unvaccinated ones that is the measure for herd immunity and therefore risk of an outbreak. By utilizing the percent exempt, the diverse enrollment numbers in Illinois schools are controlled. Using percentages to measure vaccination levels is common within the United States -- the CDC uses percentages as goals for vaccination levels and Healthy People 2020, a federal health program, has set percentage vaccination goals to measure vaccination success (Department of Health and Human Services 2015b; Seither et al. 2015).

In addition to MAUP, boundary areas could impact this research in the form of edge effects. An edge effect occurs when point data occurs near boundary areas and is impacted by data outside the study area. By studying schools in conjunction with the schools nearest them, schools near the Illinois boundary with five contiguous states may have closer neighbors outside of Illinois and could be susceptible to the edge effect. Illinois has multiple schools near state boundaries that may have transboundary impacts. The population of East St. Louis, for example, is part of the Greater St. Louis metropolitan area and is likely more aligned with Missouri than with Illinois, even though the city and school district falls under Illinois jurisdiction. The administrative boundary of Illinois is fixed, but population flow is fluid; by only studying schools within the Illinois boundaries, this thesis may miss local-scale patterns and trends in boundary regions. There is no feasible way to determine if any students cross borders to attend schools;
however, this would only be plausible for private schools and a very small proportion of the data.

**Data Cleaning**

To procure the vaccination and exemption data both the 2003-2004 and 2013-14 Excel files were downloaded from the ISBE website on 25 May 2015 (2015e). These reports compile data on the polio, DTP, TDAP (2013-2014 data only), measles, mumps, rubella, hepatitis B, HiB, and varicella vaccines, sorted by school. Each vaccine reports data on the numbers of students that are vaccinated, have a religious exemption, have a medical exemption, are not vaccinated but are scheduled for vaccination, and are unvaccinated/noncompliant. In conjunction with vaccination requirements, Illinois also requires each student to undergo a physical examination. These numbers are reported within the vaccination data but will not be discussed, as they are outside the scope of this thesis.

There are differences in the format of the 2003-2004 and 2013-2014 data, requiring slightly different geolocating and data cleaning processes. For the 2013-2014 school year the data contained the school name, RCDTS code, district, total facility enrollment, and vaccination information. Varicella data is reported for all students except for 12th grade, as these students did not need to be vaccinated against varicella when they were in kindergarten. However, some schools that include 12th graders report varicella numbers for all students even though it is not required by the state.

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13 The varicella vaccine was added to immunization requirements by the Illinois Department of Public Health for kindergartners who started school in the 2002-2003 school year. Students who were in 12th grade in the 2013-2014 school year were in first grade at that time (Illinois State Board of Education 2003).
To geolocate the schools, both public and private school data were downloaded from the National Center for Education Statistics MapEd program, a database that contains street addresses and latitudes/longitudes for each school (NCES 2015). The ISBE vaccination data were manually matched with the geolocation data using school names.

Incidences of schools sharing the same name required one or two additional steps to geolocate, depending on whether they are private or public schools. For public schools, duplicate names were matched using the address from the NCES data and the school district from the ISBE data. When necessary, Google and Google Maps were utilized to confirm that schools were geolocated correctly. For private schools with the same name, the district could not be used as a reference, as the ISBE data does not include a specific district for private schools. To alleviate this issue, the Illinois Education Directory RCDTS Lookup for 2013-2014 was downloaded (Illinois State Board of Education 2015b). Using this directory, the RCDTS codes were matched to get the address of the school. The address was then converted into latitude/longitude using a geocoding tool (Zwiefelhofer 2015) and manually entered into the geolocated database. Of the 4,881 schools in the data set, 20 were unable to be geolocated using the NCES data or the RCDTS 2013-2014 directory. For 17 of these schools the RCDTS code from the 2003-2004 data was used to geolocate. The remaining three schools\(^{14}\), containing 369 students (0.00016% of total Illinois student population) were unable to be geolocated.

The 2003-2004 data did not contain school names, only the RCDTS code, total facility enrollment and vaccination information. The varicella vaccine is only reported for some schools for reasons outlined above. To geolocate the 2003-2004 data two documents (the RCDTS 2003-

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\(^{14}\) The schools are: Grace Christian Academy (168 students), Hope Lutheran (85 students) and St. Marys (116 students)
2004 directory and the previously geolocated 2013-2014 ISBE data) were cross-referenced to
match the school names and addresses with the RCDTS code. There were 40 RCDTS codes that
were unable to be identified using these references and an internet search. The 40
unidentifiable schools contain 10,864 students (0.0045% of the total student population). For
the schools that were identified with the RCDTS directory the latitude/longitude coordinates
were found using the same website (Zwiefelhofer 2015). Three schools in the data were
duplicates, and they were removed from the data.\(^\text{15}\)

Once all the schools were geolocated for both school years, the percent of the student
population with a religious exemption was calculated. Varicella calculations were only
computed for the 2013-2014 school year. Since not all students were required to be vaccinated
against varicella, the percent with a religious exemption was calculated using the total number
reported by the school (protected, unprotected, medical exempt, religious exempt and
approved scheduled) for varicella instead of the total enrollment number. There were four
private schools\(^\text{16}\) with a combined total of 63 students that did not report any varicella data;
these schools were removed from the varicella statistical tests.

**Data Limitations**

There are several limitations associated with the data. First, there are schools missing
from the data in addition to the 43 that were not geocoded. In the 2013-2014 data report, ISBE

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\(^\text{15}\) The duplicate school reported were: Thompsonville Grade School, Thompsonville High School and
Lemont Township High School
\(^\text{16}\) The schools that did not report any varicella data are: Academic Mastery Academy (1 student), Junior
Achievers Christian Academy (15 students), Vincent Grey Academy (35 students) and Youthbuild Academy
(12 students).
noted that one entire school district was excluded from the data because incorrect reporting led to the inability to identify below the district-level. The 2013-2014 Illinois school district summary identifies 5,035 schools, but the vaccination data only includes 4,881 schools. The reported 2003-2004 school numbers cannot be compared to the total number of schools because the district summary for this school year only reported public schools. Other nuances from the 2003-2004 data collection process are no longer accessible as the 2003-2004 ISBE summary report no longer exists (Vanover 2015). The lack of vaccination data for all schools could affect the spatial analysis of exemption trends.

In addition, ISBE identified in the 2013-2014 report that the data collection portal has potential to duplicate counts in multiple fields, likely resulting in an overestimation of the number of noncompliant or unvaccinated students when compiling vaccination data for each school. This thesis centers on religious exemptions by vaccine, where the likelihood of double counting a student is lower, but it could slightly alter total numbers.

All vaccination data is reported at the school level and does not account for different grade level populations. This thesis does not discuss the TDAP, HiB or hepatitis B vaccination data because these vaccines are only recommended for certain age groups/grade levels. HiB is required for pre-kindergarten only, TDAP for students in grades 6-12, hepatitis B for students in pre-kindergarten and grades 5-12 (Illinois State Board of Education 2014; CDC 2015a). The data does not contain by-grade enrollment numbers, making it impossible to determine the total number of students that require these vaccinations (and therefore the percentage of students with a religious exemption). In addition, ISBE identifies that some schools report vaccination data for diseases for all grades even if the vaccine is not required. For example, one public school district reported HiB data for all K-12 students, even though HiB is not required after pre-
kindergarten. By removing HiB, TDAP and hepatitis B from analysis, only a portion of vaccination exemption patterns can be determined. Since exemptions are required for each vaccine, excluding these vaccines could alter the analysis since children could be exempt only from excluded vaccinations, but still count as exemptions in the overall numbers for that school. Parents’ perception of risk of a particular vaccine can influence their desire to get an exemption and risk varies by vaccine (Reich 2014) — a 1999 study found that parents were more likely to refuse hepatitis B and varicella over vaccines that they perceived as “more threatening” such as measles and HiB (Largent 2012).

Low enrollment numbers could alter the results of this study. ISBE does not have a minimum enrollment number in order to include the school’s vaccination data. Since this study uses the percentage of students with an NME for each vaccine, low enrollment numbers could skew the results if some of these students have exemptions. These low-enrollment schools make up a very small proportion of the total number of schools, for the 2003-2004 school year, there were 39 schools with less than 10 students, including twelve schools with only one student. For the 2013-2014 school year there were 20 schools with less than 10 students and only one school with one student.

This study does not account for students that are homeschooled. Children that are homeschooled are not required to follow Illinois vaccination laws and therefore not required to procure a religious exemption, so no data exists for this population. Lack of data on homeschooled children is not atypical, and is the main barrier to all types of research on homeschooled children (Isenberg 2007). However, Kennedy and Gust (2005) found that homeschooling families may be more concerned about vaccine safety than non-homeschooling families, possibly leading to lower vaccination rates. Illinois does not require homeschooled
children to register with the state, making it impossible to determine how many children are missing from the data because they are homeschooled (Illinois State Board of Education 2015d).

Lastly, Illinois allows for students to attend school and remain within vaccination compliance standards if they are scheduled for completion of a vaccination series. To be considered within compliance, the parent must provide a schedule for the completion of the vaccination series and a statement of rationale for the delay (Illinois General Assembly 2014). These students are annotated in the “approved/scheduled” data column by vaccine. For 2013-2014 the percent of approved/scheduled students ranged from 0.22% to 0.30% for Polio, DTP, Measles, Mumps and Rubella (Illinois State Board of Education 2014). Local administrations are responsible for following up with these students to ensure they complete the required vaccinations. If they do not complete the vaccination as scheduled, the child is considered noncompliant and should be excluded from school as per 105 ILCS 27/8.1. The state places all responsibility on follow up and exclusion on local school authorities. Unsurprisingly, studies on school nurses and administrations have shown that following up on health requirements is not always conducted and in some cases, administrations avoid excluding students in order to not upset parents (Salmon, Omer, et al. 2005; Allen 2007). Schools with a dedicated health professional are more likely to prioritize health requirements and follow up on students with outstanding requirements (Salmon et al. 2004). Potentially, in a school where there is no follow-up to scheduled vaccinations, a student could avoid getting a vaccination or procuring an exemption. The likelihood of this occurrence is unknown.
Methods

The current NME data Illinois maintains is formatted as individual schools or aggregated at the school district level. In the event that the state would need to identify areas with higher percentages of unvaccinated children, such as an outbreak or epidemic, the current data is not easily accessible or useful. Examining more than 5,000 schools individually is time-intensive. Data aggregated according to administrative boundaries such as school districts could present an inaccurate picture by removing private schools from the analysis. In addition, many Illinois school districts have overlapping boundaries, creating difficulties in conducting a spatial analysis at the district scale. This thesis explores spatial analysis methods to determine if NME clusters exist and identify their location. Clusters, rather than individual schools, are the fastest way to identify high- and low-priority areas in the event of an outbreak of a disease, not individual schools or administrative scales.

The goal of this thesis is to identify statistically significant areas of high and low vaccination rates to determine if there are spatial patterns of vaccination exemption within Illinois using multiple cluster detection methods and weighting models. To reach this goal, the following research questions will be addressed: are there spatial clusters of hot and cold spots of vaccination exemptions? If so, where are they located? How do the clusters vary by detection method and weight? The answers to these questions will be determined using a variety of statistical tools available in ArcGIS 10.2.2 (ESRI 2014). To determine if spatial clustering is present, the Getis-Ord General G statistic will be used to measuring high or low clustering. To determine where the hot and cold spot clusters are located the Getis-Ord Gi* statistic will be used and Anselin local Moran’s I will be utilized to identify hot spots, cold spots and spatial outliers. These tools compute a z-score and p-value. The z-score is the standard deviation and
the p-value is the probability that the null hypothesis [complete spatial randomness (CSR)] is correct, meaning that all the point locations and associated exemption values are completely arbitrary.

Both the Getis-Ord $G_i^*$ and Anselin local Moran’s $I$ tests are being used in this thesis in order to determine which test would be most useful for easy identification of NME clusters. Cluster morphology is highly complex, often leading to the use of multiple clustering methods to determine which is best for the specific research. Multiple clustering methods were successfully used in the identification of local clustering of cancers on Long Island (Jacquez and Greiling 2003) and identified spatial patterns of breast cancer in Michigan (Meliker et al. 2009). By utilizing two different clustering approaches, this thesis will compare different methods for cluster detection and identifying the strengths and weaknesses of both.

Prior to conducting any statistical tests on the data, models will be created to quantify spatial relationships in the form of spatial weights matrices. These models set parameters for cluster detection. The schools closest to other schools are referred to as neighbors. For this thesis, the parameters will consist of two models: nearest neighbors and a hybrid consisting of distance thresholds and nearest neighbors. A single distance threshold parameter will not be used due to major differences in distances between rural and urban school neighbors.

The $K$ nearest neighbors spatial relationship creates a formula where a specific number of neighboring points are paired with the target point; typically a minimum of eight neighbors is suggested to compute a reliable $z$-score (ESRI 2016a). These relationships will have many different distance radii – schools in urban areas will have small distances and those in rural areas can cover many miles. Utilizing the closest points instead of all points within a specified distance is useful for this thesis because the spatial analysis will adjust to density between the
rural and urban areas. For this thesis, eight neighbors will serve as the variable in the nearest neighbors spatial relationship model (8NN). Choosing an appropriate k value is important for appropriate cluster detection as too few or too many neighbors will skew results. As a general rule of thumb, it is better to have fewer than too many neighbors (Getis and Aldstadt 2010). Getis and Ord recommend a minimum of eight neighbors for Gi* statistics (1992). ESRI recommends that each point have an average of eight neighbors with no more than 1,000 neighbors (2016a). The commonly used geometric queen contiguity spatial weight matrix uses eight neighbors but is more commonly used with polygons and requires a shared boundary or vertex (Getis and Aldstadt 2010). Although not as common as a distance threshold, k nearest neighbors has successfully been used as a parameter for cancer spatial cluster analysis (Meliker et al. 2009) and identifying hot spots of vaccination exemptions in California (Carrel and Bitterman 2015).

Distance thresholds specify a cutoff distance so that each point (school) will be linked to all other schools within the specified Euclidian distance. It is important to select a distance threshold where each school has at least one neighbor, but does not have too many neighbors. Too few or too many neighbors in a calculation produces an unreliable z-score. The data for this thesis contains both dense and geographically dispersed points necessitating different distance thresholds. Using a distance threshold appropriate for urban areas would result in many rural schools without neighbors. Using ArcMap’s incremental spatial autocorrelation tool, the minimum distance threshold was calculated for all data points to have at least one neighbor and the results were similar for both the 2003-2004 and 2013-2014 data sets: 15,437 meters (9.6 miles) for 2003-2004 and 15604.9 meters (9.7 miles) for 2013-2014. A 9.7-mile distance threshold within the city of Chicago is unreasonable because there are multiple schools that
have over 1000 neighbors. Since a pure distance threshold relationship model is inappropriate for this data, a model has been created that is a hybrid of both distance thresholds and nearest neighbors relationships.

The nearest neighbors relationship is important because it analyzes the schools closest to one another. However, in a dense urban area like the City of Chicago, there are many schools in close proximity to one another. Measuring only the eight nearest schools could omit patterns and trends. By creating a hybrid model that incorporates distance, urban areas can be effectively analyzed while still including all schools in the dataset. For this model all schools will have a minimum of eight neighbors even if the distance threshold has to be increased to include them. The distance threshold is only overridden when the minimum number of neighbors is not met.

To select an appropriate distance threshold for urban areas using the hybrid model, ArcMap’s incremental spatial autocorrelation tool was used. This tool can be used to help determine an appropriate value for a distance threshold by measuring spatial autocorrelation for multiple distances and reporting z scores and p values for each distance. This tool identifies statistically significant peak z scores that indicate the distance recommended for cluster detection. Incremental spatial autocorrelation has been used to select appropriate distances to identify WIC-eligible women in California (Stopka et al. 2013), patterns of West Nile Virus incidence in Iowa (DeGroote et al. 2008) and to identify an appropriate distance for hot spot analysis of social media content in response to a Wyoming fire (Kent and Capello 2013).

To determine an appropriate distance threshold for Chicago – the densest area of data – the incremental spatial autocorrelation tool recommended a distance threshold of 3760.31 meters (2.3 miles). For the details of this computation see Appendix A. 3760.31 meters will be
the distance for the distance threshold for the hybrid model. Once the 8NN and the hybrid spatial relationship models are created as spatial weights matrices they will be used as the parameters for all statistical tests.

The Getis-Ord General G will be used to measure high and low clustering. The results of this statistic must be interpreted within the context of the null hypothesis. The null hypothesis for General G is that there is no spatial clustering of vaccination exemption rates; these values exhibit CSR. The math for computing Getis-Ord General G is located in Figure 3.1. If the p-value is statistically significant, the null hypothesis can be rejected. A positive z-score indicates clustering of high values, a negative z-score a clustering of low values (ESRI 2016c). The General G statistic only identifies if clustering is present; it does not locate clusters.

\[
G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}x_i x_j}{\sum_{i=1}^{n} \sum_{j=1}^{n} x_i x_j}, \quad \forall j \neq i
\]  

(1)

where \(x_i\) and \(x_j\) are attribute values for features \(i\) and \(j\), and \(w_{i,j}\) is the spatial weight between feature \(i\) and \(j\). \(n\) is the number of features in the dataset and \(\forall j \neq i\) indicates that features \(i\) and \(j\) cannot be the same feature.

The \(z_G\) score for the statistic is computed as:

\[
z_G = \frac{G - E[G]}{\sqrt{V[G]}}
\]

(2)

where:

\[
E[G] = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}}{n(n - 1)} , \quad \forall j \neq i
\]

(3)

\[
\]

(4)

Figure 3.1. Getis-Ord General G Statistic
(Source: ESRI 2016c).

To locate clusters the Getis-Ord Gi* statistic will conduct hot spot analysis. Hot spot analysis calculates a value for each point within the context of other points specified in the parameters. Statistically significant hot spots are identified when the value is too large to be a result of random chance (Getis and Ord 1992; Ord and Getis 1995). The official calculation for
the Gi* statistic is listed in Figure 3.2. Getis-Ord Gi* statistic calculates a z-score and p-score with confidence levels of 90, 95 and 99 percent for each data point, that can be visualized in ArcMap (ESRI 2016d). The Getis-Ord Gi* tests is commonly used to identify hot and cold spots including local crime patterns in the United Kingdom (Craglia, Haining, and Wiles 2000) and traffic congestions clusters in India (Prasannakumar et al. 2011). Getis-Ord Gi* is also commonly used in public health studies including patterns of sexually transmitted disease, tuberculosis transmission and West Nile Virus (Brouwer et al. 2012; Haase et al. 2007; DeGroote et al. 2008),

$$G_{i}^{*} = \frac{\sum_{j=1}^{n} w_{i,j} x_{j} - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S} \sqrt{\frac{n \sum_{j=1}^{n} w_{i,j}^{2} - (\sum_{j=1}^{n} w_{i,j})^{2}}{n-1}}$$

(1)

where $x_{j}$ is the attribute value for feature $j$, $w_{i,j}$ is the spatial weight between feature $i$ and $j$, $n$ is equal to the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_{j}}{n}$$

(2)

$$S = \sqrt{\frac{n \sum_{j=1}^{n} x_{j}^{2} - (\bar{X})^{2}}{n}}$$

(3)

The $G_{i}^{*}$ statistic is a z-score so no further calculations are required.

Figure 3.2. Getis-Ord Gi* Statistic
(Source: ESRI 2016d).

Anselin local Moran’s I is similar to the Getis-Ord Gi* statistic in that it also identifies hot and cold spots and it also identifies statistically significant spatial outliers, defined as a high value surrounded by low values or vice versa (Anselin 1995). Spatial outliers indicate a unique situation and are worth investigating in the analysis. Anselin local Moran’s I calculates a local Moran’s I value in addition to the z-score and p-value. Calculations for the statistic are located in Figure 3.3 (ESRI 2016b). A positive I value indicates a cluster; a negative value is an outlier. This statistic is commonly used within spatial epidemiology including detecting local clusters and
outliers of cancer on Long Island (Jacquez and Greiling 2003) and classifying clusters and outliers of personal belief vaccination exemptions in California schools (Carrel and Bitterman 2015). The Getis-Ord Gi* statistic and Anselin local Moran’s I are commonly used together in spatial analysis, examples include diabetes and obesity research (Penney et al. 2014; Grubesic, Miller, and Murray 2014).

The Local Moran’s I statistic of spatial association is given as:

\[ I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j} (x_j - \bar{X}) \]  

(1)

where \( x_i \) is an attribute for feature \( i \), \( \bar{X} \) is the mean of the corresponding attribute, \( w_{i,j} \) is the spatial weight between feature \( i \) and \( j \), and:

\[ S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} (x_j - \bar{X})^2}{n-1} \]  

(2)

with \( n \) equating to the total number of features.

The z-score for the statistics are computed as:

\[ z_{I_i} = \frac{I_i - E[I_i]}{\sqrt{V[I_i]}} \]  

(3)

where:

\[ E[I_i] = -\frac{\sum_{j=1, j \neq i}^{n} w_{ij}}{n-1} \]  

(4)

\[ V[I_i] = E[I_i^2] - E[I_i]^2 \]  

(5)

\[ E[I_i^2] = A - B \]  

(6)

\[ A = \frac{(n - b_{2i})}{n - 1} \sum_{j=1, j \neq i}^{n} w_{i,j}^2 \]  

(7)

\[ B = \frac{(2b_{2i} - n)}{(n - 1)(n - 2)} \sum_{k=1, k \neq h}^{n} \sum_{h=1, h \neq i}^{n} w_{i,k}w_{i,h} \]  

(8)

\[ b_{2i} = \frac{n}{\sum_{i=1, i \neq j}^{n} (x_i - \bar{X})^4} \left( \frac{n}{\sum_{i=1, i \neq j}^{n} (x_i - \bar{X})^2} \right) \]  

(9)

Figure 3.3. Anselin Local Moran’s I Statistic

(Source: ESRI 2016b).
Table 3.1 shows all 66 statistical tests that will be conducted. Once all the statistical tests are completed, temporal shifts and patterns will be analyzed. Expected results include finding clusters of exemptions throughout Illinois with more clusters for the 2013-2014 school year. In addition, finding cold spots in urban areas and hot spots in both urban and rural areas is anticipated. Expectations are that cluster locations will differ between the 8NN and the hybrid parameters. It is also anticipated that the Anselin Local Moran’s I will identify outliers and clusters in both urban and rural areas that mirror the patterns identified in the Getis-Ord Gi* results, providing greater insight as to what causes a hot or cold spot.

Table 3.1 List of Statistical Tests

<table>
<thead>
<tr>
<th>Stats Test</th>
<th>School Year</th>
<th>Models</th>
<th>Vaccines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Getis-Ord General G</td>
<td>2003-2004</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
</tr>
<tr>
<td>Getis-Ord General G</td>
<td>2013-2014</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
</tr>
<tr>
<td>Getis Ord-Gi*</td>
<td>2003-2004</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
</tr>
<tr>
<td>Getis Ord-Gi*</td>
<td>2013-2014</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
</tr>
<tr>
<td>Aneslin Local Moran's I</td>
<td>2003-2004</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
</tr>
<tr>
<td>Aneslin Local Moran's I</td>
<td>2013-2014</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
</tr>
</tbody>
</table>
Chapter 4

Statistical Test Results and Discussion

This chapter addresses the results of all statistical tests described in Chapter 3 followed by a discussion and interpretation of the results. The results are presented and interpreted in the following order: Getis-Ord General G and Getis-Ord Gi* and Anselin Local Moran’s I. Figure 4.1 provides a spatial perspective of the location of all schools in Illinois for both school years addressed in this thesis. Figure 4.2 provides better context of the schools located in the greater Chicago area. This chapter concludes with a summary discussing the key findings and merits of each statistical test.
Figure 4.1. Change in Location of Illinois Schools, 2003-2004 and 2013-2014 School Years
Figure 4.2. Change in Location of Chicago-Area Schools, 2003-2004 and 2013-2014 School Years
Getis-Ord General G Results

The Getis-Ord General G Statistic measures the presence of spatial clustering. Each time a General G test is run in ArcMap, a high-low clustering report is produced. This report includes the expected General G, observed General G, the z-score and the p-value (Figure 4.3). Each report includes the same reference bell curve, p-value and z-score chart. Summary tables showing the results for this test are shown in Tables 4.1 and 4.2.

All tests for both parameters reported high spatial clustering and a p-value of zero. The z-scores for the Getis-Ord General G varied but all were above the threshold for 99% statistical significance (2.58). For the 8NN parameter, the lowest z-score was 5.743 (2003-2004 polio) and the highest was 9.4 (2013-2014 polio). For the hybrid parameter, the lowest z-score was 6.976 (2003-2004 measles) and the highest was 10.460 (2013-2014 polio). The lowest z-score for 2013-2014 was 6.501, measles with the 8NN parameter. The highest z-score for 2003-2004 was 7.507, rubella with the 8NN parameter.

The change in clustering was not consistent over time: for the 8NN parameter, polio was the only vaccine that z-score increased from 2013-2014. DTP, measles, mumps and rubella had z-scores in 2013-2014 that were lower than the 2003-2004 z-scores, although still well above the 2.58 critical threshold for high clustering. For the hybrid parameter, the z-scores increased in all vaccines from the 2003-2004 school year to the 2013-2014 school year.

For both parameters, the largest temporal change in z-score occurred with polio vaccine exemptions. For the 8NN parameter, the greatest difference in z-scores from 2003-2004 to 2013 to 2014 was a change of +3.657 for the polio vaccine. For the hybrid parameter the greatest change was +3.027.
Although z-scores decreased for some vaccines between 2003-2004 and 2013-2014 for the 8NN parameter, the average z-score increased from 7.084 in 2003-2004 to 7.467 for 2013-2014. The average z-score for the hybrid parameter also increased from 7.139 to 7.200. These averages were calculated without including the varicella 2013-2014 data since it is not included in the 2003-2004 average.

Figure 4.3. High-Low Clustering Report for Mumps Exemptions 8NN Model, 2003-2004 School Year
Table 4.1 Getis-Ord General G Statistic Results for Eight Nearest Neighbors Parameter

<table>
<thead>
<tr>
<th>School Year</th>
<th>Spatial Clustering?</th>
<th>High or Low?</th>
<th>z-score</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>5.743</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>9.400</td>
<td>0</td>
</tr>
<tr>
<td>DTP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.242</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>7.156</td>
<td>0</td>
</tr>
<tr>
<td>Measles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.466</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>6.501</td>
<td>0</td>
</tr>
<tr>
<td>Mumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.463</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>7.089</td>
<td>0</td>
</tr>
<tr>
<td>Rubella</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.507</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>7.191</td>
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</tr>
<tr>
<td>Varicella</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>6.600</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.2. Getis-Ord General G Statistic Results for Hybrid Parameter

<table>
<thead>
<tr>
<th>School Year</th>
<th>Spatial Clustering?</th>
<th>High or Low?</th>
<th>z-score</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.433</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>10.460</td>
<td>0</td>
</tr>
<tr>
<td>DTP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.171</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>8.420</td>
<td>0</td>
</tr>
<tr>
<td>Measles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>6.976</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>7.788</td>
<td>0</td>
</tr>
<tr>
<td>Mumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.030</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>8.176</td>
<td>0</td>
</tr>
<tr>
<td>Rubella</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>Yes</td>
<td>High</td>
<td>7.085</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>8.358</td>
<td>0</td>
</tr>
<tr>
<td>Varicella</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013-2014</td>
<td>Yes</td>
<td>High</td>
<td>7.403</td>
<td>0</td>
</tr>
</tbody>
</table>
Getis-Ord General G Statistic Discussion

The Getis-Ord General G statistical tests confirmed the hypothesis that there is spatial clustering of NMEs in Illinois schools. This clustering varies by school year and by vaccine type but all tests indicated high-level clustering. Using the 8NN and the hybrid parameters, all vaccines for both school years exhibited high spatial clustering with a p-value of zero, indicating that there is over a 99% chance that the vaccine NME rates are not random (see Tables 4.1 and 4.2). Since high rates of NMEs are more spatially clustered than are expected at random the null hypothesis of complete spatial randomness can be rejected.

The z-score measures standard deviation; positive values measure high-value clustering and negative values indicates low-value clustering. All results from this analysis produced positive z-scores, indicating high-value clustering. For a 99% statistical significance for high-value clustering the minimum z-score is 2.58. For both school years, the z-scores all well above the 2.58 threshold – the z-score range is 5.743 to 10.460. These high z-scores further support the rejection of the null hypothesis as they are located in the tails of a normal distribution (see Figure 4.3).

Although all z-scores indicate high-value clustering, there is merit in further analysis. For the 8NN parameter the z-scores for the DTP, measles, mumps and rubella vaccines all remained within 1 standard deviation between the two school years. For the hybrid model the largest change in these vaccines was 1.3 standard deviations. This indicates that the clustering was relatively consistent over time. However, for the polio vaccine the z-score increased 3.7 standard deviations for the 8NN parameter, meaning that polio NMEs are much more clustered in 2014 than they were in 2003. The polio temporal increase was also consistent with the hybrid parameter with an increase of 3 standard deviations. Many questions arise as to why polio had
such an increase in clustering compared to the other vaccines. One hypothesis is the overall
decrease of polio globally, giving parents a safer sense of security surrounding the disease. Polio
is closer to eradication and has the lowest incidence rates than any other vaccine required for
school-entry. In 1988 the World Health Organization launched a global drive to eradicate polio
and declared the Americas polio-free in 1994 (Moturi et al. 2014; CDC 2016b). In 2014 there
were only three countries in the world that had endemic wild polio virus – Afghanistan, Pakistan
and Nigeria (Moturi et al. 2014). The decrease in wild polio virus transmission could impact a
parent’s perception of the disease and of the vaccine perhaps encouraging them to get an
exemption. Studies have shown that a reduction in incidence of a vaccine-preventable disease
often leads to the public perception that the susceptibility and severity of that disease has
decreased (Chen 1999). This change in perception could lead to more vaccine exemptions,
potentially explaining why polio exemption clusters increased much more than other vaccines.

Another interesting result of the General G statistical test is the decrease in clustering
for DTP, measles, mumps and rubella between 2003-2004 and 2013-2014 using the 8NN
parameter. For the same vaccines, the hybrid model yielded an increase in clustering. The
hybrid parameter includes all schools within the distance threshold of 3,760 meters (2.3 miles)
or a minimum of eight neighbors. For the schools that do not have eight neighbors within a 2.3-
mile radius, they are compared with the eight nearest schools, yielding the same result as the
8NN model for the individual school. The hybrid model produces a different result than the 8NN
model because of the NME patterns within the distance threshold. Therefore, for the General G
statistical test, there was more clustering occurring in areas with higher school densities than in
areas of Illinois with school density lower than eight schools within 2.3 miles when you compare
the temporal change between school years.
Getis-Ord Gi* Results

The Getis-Ord Gi* statistical tests identify clusters using the hot spot analysis tool in ArcMap. The tool calculates a value for each school within the context of other schools specified in the parameters. The result is the identification of statistically significant spatial clusters – high values indicate hot spots of vaccination exemptions and low values are cold spots. There are three confidence levels for both hot and cold spots: 90, 95 and 99% confidence. The number of each schools by output category for the 8NN and hybrid models are located in Tables 4.3 and 4.4.

All vaccines for both models identified hot spots of 90, 95 and 99% statistical significance. The 8NN model did not identify any cold spots. The hybrid parameter identified 90% (all vaccines) and 95% (rubella and mumps only) confidence level cold spots for the 2003-2004 school year and all confidence levels for the 2013-2014 school year. For all vaccines, both models identified larger numbers of hot spots for the 2013-2014 school year than for 2003-2004. In addition, the hybrid model identified more cold spots for the 2013-2014 school year.

The remainder of the section discusses the results of the Getis-Ord Gi* statistical test starting with the hot spot results of both models for 2003-2004, followed by the cold spots. Next, the 2013-2014 hot and cold spots are discussed. This section closes with a comparison of the differences between the results of the two school years.
Table 4.3. Getis-Ord Gi* Statistic Results for Eight Nearest Neighbor Parameter

<table>
<thead>
<tr>
<th>School Year</th>
<th>99% Confidence Hot Spot</th>
<th>95% Confidence Hot Spot</th>
<th>90% Confidence Hot Spot</th>
<th>Not Significant</th>
<th>90% Confidence Cold Spot</th>
<th>95% Confidence Cold Spot</th>
<th>99% Confidence Cold Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-2004</td>
<td>98</td>
<td>58</td>
<td>39</td>
<td>5168</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>171</td>
<td>146</td>
<td>130</td>
<td>4434</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Diphtheria-Tetanus-Pertussis

<table>
<thead>
<tr>
<th>School Year</th>
<th>99% Confidence Hot Spot</th>
<th>95% Confidence Hot Spot</th>
<th>90% Confidence Hot Spot</th>
<th>Not Significant</th>
<th>90% Confidence Cold Spot</th>
<th>95% Confidence Cold Spot</th>
<th>99% Confidence Cold Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-2004</td>
<td>94</td>
<td>59</td>
<td>42</td>
<td>5168</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2013-2014</td>
<td>166</td>
<td>135</td>
<td>124</td>
<td>4456</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>

Measles

<table>
<thead>
<tr>
<th>School Year</th>
<th>99% Confidence Hot Spot</th>
<th>95% Confidence Hot Spot</th>
<th>90% Confidence Hot Spot</th>
<th>Not Significant</th>
<th>90% Confidence Cold Spot</th>
<th>95% Confidence Cold Spot</th>
<th>99% Confidence Cold Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-2004</td>
<td>116</td>
<td>45</td>
<td>56</td>
<td>5146</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2013-2014</td>
<td>156</td>
<td>161</td>
<td>122</td>
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<td>0</td>
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</tbody>
</table>

Mumps

<table>
<thead>
<tr>
<th>School Year</th>
<th>99% Confidence Hot Spot</th>
<th>95% Confidence Hot Spot</th>
<th>90% Confidence Hot Spot</th>
<th>Not Significant</th>
<th>90% Confidence Cold Spot</th>
<th>95% Confidence Cold Spot</th>
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<td>108</td>
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Rubella

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<th>90% Confidence Hot Spot</th>
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Varicella (4,877 Schools)

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Table 4.4. Getis-Ord Gi* Statistic Results for Hybrid Parameter

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<td>2013-2014</td>
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<td>3816</td>
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Diphtheria-Tetanus-Pertussis

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<th>95% Confidence Cold Spot</th>
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<td>69</td>
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<td>2013-2014</td>
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<td>153</td>
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Measles

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Mumps

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<th>90% Confidence Hot Spot</th>
<th>Not Significant</th>
<th>90% Confidence Cold Spot</th>
<th>95% Confidence Cold Spot</th>
<th>99% Confidence Cold Spot</th>
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<tr>
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<td>69</td>
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Rubella

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<th>95% Confidence Hot Spot</th>
<th>90% Confidence Hot Spot</th>
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<td>2013-2014</td>
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Varicella (4,877 Schools)

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<th>School Year</th>
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<th>95% Confidence Hot Spot</th>
<th>90% Confidence Hot Spot</th>
<th>Not Significant</th>
<th>90% Confidence Cold Spot</th>
<th>95% Confidence Cold Spot</th>
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<td>124</td>
<td>3882</td>
<td>141</td>
<td>176</td>
<td>158</td>
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In 2003-2004 using the 8NN model, the number of hot spot schools ranged from 191 (mumps) to 217 (measles). For the hybrid model, hot spots for the 2003-2004 school year range from 194 to 264. Similar to the 8NN model, the measles vaccine had the highest number of hot spot schools, but the lowest number of hot spot schools is for polio instead of mumps. The range between the vaccine with the highest number of hot spot schools and the fewest is slightly larger for the hybrid model (26 schools) than the 8NN model (22 schools). The hybrid model identified more hot spots than the 8NN model for every vaccine except polio. For the polio vaccine, the 8NN model had one more hot spot school than the hybrid model. The other vaccines had between 43 (DTP) and 50 (rubella) additional hot spot schools identified by the hybrid model. The 8NN model identified measles with the highest number of schools in the 99% significance category (116) and DTP with the fewest (94). For the hybrid model mumps and rubella have the largest amount of 99% confidence hot spot schools (119) and polio has the lowest (70).

The hybrid model also identified cold spots, meaning that these schools have lower than expected exemption rates. For 2003-2004, cold spots were identified for all vaccines for the 90% confidence level. The highest number of total cold spots was mumps (107 schools) and the lowest was polio (19 schools). Mumps and rubella showed the same two schools (York Alternative High School and Jensen Elementary Scholastic Academy) with 95% confidence cold spots (see Figure 4.8 and Appendix C, Figures C.3 and C.5).

Hot spot cluster locations vary based on model. In general, the 2003-2004 8NN model identified hot spots in urban areas; Figure 4.4 shows measles hot spot clusters in Bloomington, Peoria, Carbondale and the greater Chicago area. The exceptions are a hot spot cluster at the predominantly rural southern tip of Illinois and a few schools southwest of Chicago. For the
hybrid model in 2003-2004, measles exemption hot spots were very similar to the 8NN model with most of the hot spots occurring in urban areas (see Figure 4.4). The biggest differences between the 8NN and hybrid models for measles exemptions occurred in the Cook County/greater-Chicago area. The hot spot locations for polio, mumps, rubella and DTP are similar to the locations of measles hot spots of the same model identified in Figures 4.4. Additional maps of exemption clusters at the state level are located in Appendix B.

The hybrid model identified one cold spot cluster located within the city of Chicago for measles (Figure 4.4). This cold spot is similar to the cold spot identified for mumps except that all schools for measles are 90% confidence. The polio and DTP exemption cold spots displayed similar spatial extent and confidence interval to the measles cold spot; the rubella cold spot is very similar to the mumps cold spot. Additional maps of exemption clusters for Chicago are located in Appendix C.

In general, there was not a lot of change in hot spot locations when comparing different vaccines of the same model for the 2003-2004 school year. Notably, for both the 8NN and hybrid models, a two-school, 90% confidence hotspot is present northeast of Peoria in the city of Roanoke for only the DTP vaccine. This can be observed by comparing Figure 4.4 and 4.5.
Figure 4.4. 2003-2004 Measles Exemption Hot Spots, 8NN results on left, Hybrid on right

Figure 4.5. 2003-2004 DTP Exemption Hot Spots, 8NN results on left, Hybrid on right
The 2013-2014 school year identified more hot spots than the 2003-2004 school year for both models for every vaccine. For the 8NN model, the total number of hot spot schools ranged from 425 (rubella and DTP) to 447 (polio). The 99% confidence schools ranged from 148 (rubella) to 171 (polio). The hybrid model identified more hot spots than the 8NN model ranging from 511 (mumps) to 533 (polio). Even though the hybrid model had more hot spots, the range between the vaccine with the highest numbers and the lowest vaccine was the same. The hybrid model also identified a higher number of 99% confidence schools than the 8NN model, DTP had the most 99% schools with 235, the lowest was polio with 210. While the hybrid model had a higher number of 99% schools for every vaccine than the 8NN model, the increase was not distributed evenly across vaccines. The polio vaccine had the smallest increase with 39 more 99% schools in the hybrid model versus the 8NN model. The rubella vaccine had the largest increase with an additional 73 schools for the hybrid 99% school results.

The hybrid model identified cold spots for all three confidence intervals for all vaccines. The vaccine with the smallest number of cold spot schools was varicella (475) and the highest was measles (543). These vaccines also had schools highest (236) and lowest (158) number of schools identified as 99% confidence level cold spots.

For the 2013-2014 school year, both models identified more hot spots in areas with lower population density. Figure 4.6 shows the locations of measles hot spots using the 8NN parameter. These locations include multiple urban areas, but also have clusters in rural regions southwest of Chicago, between Peoria and Bloomington, southeast of Urbana and east of St. Louis. For the hybrid model, hot spots are similarly dispersed throughout rural and urban areas in similar locations to the 8NN model (see Figure 4.6). The addition of cold spots in the hybrid model is the largest difference between the 8NN and hybrid results. For the 2013-2014 school
year, the hybrid model identified cold spots primarily in the urban areas of Chicago, Waukegan and Peoria. Figure 4.6 shows the cold spot locations for measles. Other vaccines have cold spots very similar to measles. All vaccines identified only one 99% confidence cold spot, located within the city of Chicago.

For this school year, there was some spatial variability between vaccines of the same model. There are many instances; this section highlights two of them with additional examples visible in Appendices B and C. The 8NN parameter has different results in the vicinity of Carbondale (Figure 4.7). For the polio exemptions, there is an eight-school 90% cluster. These same schools plus one additional create a 95% cluster for varicella exemptions. However, DTP, measles, mumps and rubella do not have any clusters in this region. Figure 4.7 compares the hot spots identified for varicella versus those for polio and for mumps using the 8NN 2013-2014 model. For the hybrid model, there are different locations of hot and cold spots in the Chicago area. There is an eight school hot spot for mumps in the Park Ridge/Niles suburb of Chicago. This hot spot is only two schools for rubella and is absent for measles (Figure 4.8). In addition to the hot spot variations, the large cold spot in Chicago extends into the western suburb of Oak Park for only the measles vaccine also visible in Figure 4.8.
Figure 4.6. Measles exemption clusters, 2013-2014 school year, 8NN results on left, Hybrid on right
Figure 4.7. 8NN results for Varicella, Polio and Mumps for the 2013-2014 School Year
Figure 4.8. Differences in Locations for Measles, Mumps and Rubella Exemptions in Chicago
For both models, the number of hot spots in 2013-2014 increased from the 2003-2004 results. The number of cold spots in the hybrid model also increased for the 2013-2014 school year. The number of hot spot schools identified for the 2013-2014 school year 8NN model were more than double the number of schools identified in the 2003-2004 school year for every vaccine except measles. For the 8NN model polio vaccine exemptions had the largest increase in hot spots: 195 schools were identified in 2003-2004, 447 schools in 2013-2014. Measles exemptions had the smallest increase, growing from 217 to 429 schools. Similar to the 8NN model, the number of hot spot schools for the hybrid model in 2013-2014 more than doubled the 2003-2004 school numbers. For the hybrid model, the vaccines with the largest and smallest increases in hot spots were the same as the 8NN model, polio (339) and measles (229). Polio had the largest increase in cold spots (513 schools) and mumps had the smallest increase (408 schools).

In addition to the number of hot and cold spots increasing for every vaccine, there were spatial differences between the 2003-2004 and 2013-2014 results. For both parameters the 2003-2004 hot spots were located mostly in urban areas; for 2013-2014 they were located in multiple urban and rural areas (Figures 4.9 and 4.10). Some areas, for example the city of Dolton, had hot spots in 2003-2004 hybrid model that were identified as cold spots in 2013-2014 (see Figure 4.11). In the same figure, it is possible to see that hot spots in certain areas were present in 2003-2004 and absent in 2013-2014, as seen in the western Chicago suburbs of Oak Park and Forest Park.

For the hybrid model, the cold spot locations moved beyond the boundaries of the city of Chicago; however, they remained in predominately urban areas (Figure 4.10). Within the city of Chicago, the initial cold spot grew and another smaller cold spot appeared in the
southeastern part of the city near the Indiana border (see Figure 4.11). The cold spot locations within Chicago were similar across vaccines; for a complete repository of all Chicago hot spot maps see Appendix C.
Figure 4.10. Change in Rubella Hot and Cold Spots, Hybrid Model

Figure 4.11. Comparison of Hybrid Model Rubella Exemption Clusters in Chicago
Getis-Ord Gi* Discussion

The results of the Getis-Ord Gi* statistical tests require temporal and spatial analysis to further understand exemption patterns in Illinois. This section is separated by model, first discussing the results and temporal differences with the 8NN model. Then, the hybrid model results will be investigated. This section concludes with comparing the differences in results between models.

For the 2003-2004 school year, 8NN model, hot spots were identified in mainly urban areas of Illinois. As expected, the majority of schools were not part of an exemption cluster; only 3.7% to 4.0% of the schools were classified as statistically significant depending on the vaccine tested. The 99% statistically significant schools had even smaller percentages ranging from 1.8% (DTP) to 2.2% (measles) of the total number of schools. For the 2013-2014 school year there were 482 fewer schools than in 2003-2004 and the 8NN model identified more hot spots. Overall, 2013-2014 the number of hot spot schools ranged from 8.7% to 9.2% and the 99% confidence schools ranged from 3% to 3.5%.

It is noteworthy that the number of hot spot schools increased 5% in ten years. During this same time, the percentage of students in Illinois with religious exemption grew from 0.2% to 0.6% (Illinois State Board of Education 2003; Illinois State Board of Education 2014). Even though the percentage of children with exemptions is increasing, it is increasing unevenly, creating more hot spots. These hot spots are more susceptible to outbreaks during an epidemic because they have a larger portion of the population unprotected from a vaccine. These tests did not measure for herd immunity within clusters. However, hot spots schools have a higher amount of exemptions, resulting in a more susceptible population and a decreased likelihood of the presence of herd immunity within the school.
Figure 4.12. Measles Hot Spots and Population Density

Data Source: ESRI 2013b

Figure 4.13. Measles Hot Spots and Income Level

Data Source: ESRI 2013a
Spatially, hot spot clusters moved into rural and lower population density areas as well as expanded within urban areas (Figure 4.12). These lower density areas have varying median income levels, however, it appears that overall hot spots increased more in higher income areas than lower income areas (Figure 4.13). Notably, 99% hot spot clusters appeared in previously hot spot-free areas in Rock Island, Springfield, Georgetown (southwest of Urbana) and around Farina (east of St. Louis, south of Decatur). The introduction of 99% confidence hot spots in areas where there were none previously is important because it indicates that there has been some sort of change within the community or mindset of parents with regards to vaccination.

One potential reason for this shift could be media attention on the harm of vaccinations and the false Wakefield study published in March 1998 on the link between autism and the MMR vaccine. This study was heavily publicized in the media and by anti-vaccination platforms (Allen 2007, 387–388). M. J. Smith et al. found that mainstream media coverage of the link between MMR and autism influenced parental vaccine choice, increasing exemption rates (2008). Most children in the 2003-2004 school year data were already born when the false study was published. The first MMR vaccine dose is recommended by the CDC at 12 months of age (CDC 2014a). Assuming that most children are at least five years old when entering kindergarten, only children in kindergarten and first grade would have received their first MMR vaccination after the publication of Wakefield’s study. For the 2013-2014 school year, all students except for those in twelfth grade would have received their first MMR vaccine after the media hype on the disproven link between autism and vaccines.

At the state-level, The Illinois Vaccine Awareness Coalition (IVAC) is a leading activist against vaccination. Based in Oak Park, a western suburb of Chicago, the IVAC mission is “to
educate people on vaccines’ ingredients, contraindications, warnings, adverse reactions, studies, statistics, legality and personal testimony for informed vaccine choice” (“Illinois Vaccine Awareness Coalition” 2016). Founded in 1998, the IVAC has contributed to media commentary since inception (Barbara Alexander Mullarkey 1998). The IVAC has increased their online presence since 2010 with online resource for parents; the current website dates to April 2014 and provides an example of a religious exemption personal statement (“Illinois Vaccine Awareness Coalition” 2016). By providing this example, the IVAC helps make the exemption process easier for the parent as they could use this example instead of creating an individualized exemption. By making the process slightly easier, a parent could be encouraged to procure an exemption in lieu of vaccination. In addition to providing resources to parents, the IVAC has petitioned state and local officials with request to support anti-vaccination agendas (Deardorff and Jaworski 2010; “Illinois Vaccine Awareness Coalition” 2016). The overall influence of the IVAC is unknown; however, the resources for parents and the IVAC’s political work in Illinois could impact rising exemption rates.

Local media attention, as well as vocal parent groups, could also potentially have impacted the appearance of hot spots. One example of an outspoken anti-vaccination activist is Dr. David Ayoub in Springfield. In 2005-2006 Dr. Ayoub, a radiologist and associate professor at the University of Southern Illinois School of Medicine (located in Springfield), made multiple headlines as a vocal opponent of vaccines with thimerosal, similar to the disproven Wakefield Study (Borman 2006; Meg McSherry Breslin 2006; D. Ayoub 2006). In addition to news headlines, he also published commentary in the Lancet and produced a YouTube video on vaccine safety (D. M. Ayoub and Yazbak 2008; Mercury, Autism & The Global Vaccine Agenda 2005). Dr. Ayoub was also the leader of Springfield-based The Prairie Collaborative for
Immunization Safety, which no longer has an active internet presence. Although Dr. Ayoub is no longer a vocal anti-vaccination activist, his actions from 2005-2008 could have potentially shifted local views on vaccination.

In other areas there was a decrease in hot spots, a 99% hot spot in Carbondale in 2003-2004 was no longer present in the 2013-2014 results. There are many possibilities behind a hot spot disappearing. One potential explanation could be a change in mindset due to a local vaccine-preventable outbreak. There was a small mumps outbreak at the Southern Illinois University in 2006, which is located in Carbondale (Chicago Tribune 2006). Another possibility could be a lack of other like-minded parents or parenting groups. Brunson found that social networks played a key role in parents’ vaccination decisions and were more important than advice from health care providers (2013).

While most hot spots in 2003-2004 were located in urban areas, there was one 99% confidence rural hot spot at the very southern tip of Illinois. This 10-school hot spot encompassed approximately 112 square miles and grew to 17 schools in 2013-2014 with an approximate area of 277 square miles. For 2003-2004 school year there were three schools co-located in Ullin (Century Elementary, Century Junior High and Century Senior High School) that had high exemption rates. The elementary school averaged 6.6% exempt for all vaccines, the junior high averaged 5.55% and the senior high school averaged 4.65%. By 2013-2014 the junior and senior high had merged into one school, and reported an average exemption rate of 7.1% and the elementary school averaged 7.8%. These are all public schools that have a large, low-population density, catchment area. The reported NME rate create protection rates below herd immunity, making these schools more susceptible in the event of an epidemic.
The hybrid model best epitomizes the growing polarity of vaccinations. The number of total schools decreased, but the number of hot and cold spot schools increased. Proportionally, in 2003-2004 3.6% (polio) to 4.9% (measles) of the total schools were hot spots and 0.035% (polio) to 2% (mumps) were cold spot schools. In 2013-2014 these numbers rose to 10.5% (mumps, rubella and DTP) to 10.9% (polio) and 9.7% (varicella) to 11.1% (measles) respectively. There was an over 5% increase for hot spots and a 7% increase for cold spots. The 99% confidence numbers also rose; hot spots ranged from 1.3% (polio) to 2.2% (rubella and mumps) for 2003-2004 to 2.6% (DTP) to 3.8% (polio). In 2003-2004 there were zero 99% confidence cold spots, yet in 2013-2014 they ranged from 3.2% (varicella) to 4.8% (measles). The polarity is best seen by comparing the percentages of schools that were neither hot nor cold, which averaged 94% for the 2003-2004 school year and 78.7% for the 2013-2014 school year. The increased clustering of high and low NME rates is similar to findings in California (Lieu et al. 2015; Carrel and Bitterman 2015).

For 2003-2004 hot spots were identified primarily in urban areas with the exception of the previously discussed 99% confidence hot spot in the southern tip of Illinois. There are many potential explanations as to why vaccination exemption hot spots were mainly in urban areas in 2003-2004. One potential reason is access to different health care professionals. In urban areas, there are more health care providers, thus giving the community greater choice. Illinois did not require a health care provider’s signature for an exemption during these school years; they were required to have a physical exam, therefore requiring an appointment with a health care provider prior to attending school (Illinois 99th General Assembly 2015). A health care provider can turn away unvaccinated patients, or attempt to convince a parent to change his or her mind. Studies have shown that health care providers can influence parents vaccination
decisions and that trust in a health care professional is important when making vaccination
decisions (Benin et al. 2006; P. J. Smith et al. 2006; Gust et al. 2008). Anti-vaccination websites
stress the importance of finding a like-minded doctor to support an individual parent’s beliefs
(“National Vaccine Information Center” 2015; Hutchinson 2012). Some websites maintain lists
of “vaccine-friendly” doctors to help parents find providers. Dr. Sears, the celebrity doctor,
maintains a list on his website, “Ask Dr. Sears” where he provides 12 providers in Illinois, 11 of
which are located in Chicago or Chicago suburbs (Sears 2016). Having access to a health care
provider who accepts alternative vaccination schedules or unvaccinated patients could be one
reason why urban areas have more exemption hot spots.

In addition to access to anti-vaccination health care providers, parents of exempt
children have been found to use alternative or complementary medicinal practitioners such as
chiropractors, acupuncturists or herbalists that can offer anti-vaccination views (Salmon,
Moulton, et al. 2005). There are likely more alternative medicine practitioners in areas with
greater population density, which also could contribute to the presence of hot spot clusters.
The presence of hot spot clusters in lower population density areas in 2013-2014 could
represent an increase in healthcare alternatives or like-minded doctors. The CDC reported an
increase in people seeking alternative medicine options between 2002-2007 and that trend has
continued to the present (Barnes, Bloom, and Nahin 2008).

Some areas had a decrease in hot spots, such as the west Chicago suburbs. One
potential reason that a hot spot disappeared could be due to increased awareness of the
hazards of infectious disease. Between the 2003-2004 and 2013-2014 school years, there were
multiple outbreaks of vaccine-preventable diseases. In 2006 there were multiple mumps
outbreaks across the state, mostly at universities including at Wheaton College, located in the
Chicago suburb of Wheaton (Nilsson 2006). During the 2006-2007 school year there was a pertussis outbreak in an unnamed Cook County high school with 36 confirmed cases (CDC 2008a). In 2008 a 30-case measles outbreak occurred in the greater Chicago area encompassing suburban Cook, DuPage and Lake County; 25 of these cases were in school-aged children, all of who were unvaccinated and homeschooled (CDC 2008b). In 2009 there was another pertussis outbreak linked to multiple schools in Evanston (NBC Chicago 2009). In addition to these outbreaks, in 2012 Illinois reported the highest numbers of pertussis cases since 1950 (Illinois Department of Public Health 2013).

These outbreaks could also contribute to the increase in the cold spots located in Chicago. The increase in cold spots is interesting, especially since the proportional increase of cold spots was much more than the increase in hot spots. Media attention so often surrounds the anti-vaccination platform, instead of the increased polarity and clustering of vaccination choice.

The one cold spot identified for 2003-2004 is located on Chicago’s West Side encompassing five of Chicago’s official 77 neighborhoods: East and West Garfield Park, North and South Lawndale and Humboldt Park (Figure 4.14). These neighborhoods are known for high crime rates; West Garfield Park, North Lawndale and East Garfield Park have the top three violent crime rates when comparing statistics for all Chicago neighborhoods. They are also the top three for quality-of-life crimes, and Humboldt Park ranks fifth (Chicago Tribune 2016). These neighborhoods have high poverty rates; East Garfield Park had 42.4% and North Lawndale had 43.1% of households living below the poverty level as of the 2010 Census. Figure 4.14 shows the 2003-2004 Rubella hot and cold spots by census block median household income for 2012 (ESRI 2013a).
The two schools identified as 95% confidence cold spots for mumps and rubella were York Alternative High School and Jensen Elementary Scholastic Academy (currently named Jensen Miller Scholastic Academy). York Alternative High School is a unique school as it is located inside the Cook County Jail and therefore students are not eligible for exemptions. While this school contributes to the presence of the Chicago cold spot, it is part of a larger pattern of low exemption rates within Chicago. The other 95% confidence cold spot school, Jensen, is a magnet, public K-8 school in the neighborhood of East Garfield Park. For the 2015-2016 school year, Jensen’s students were 96.7% low income and 95.4% African American (Chicago Public School District 2016b).

For the 2013-2014 school year, cold spot schools were identified in most of Chicago’s west and northwestern neighborhoods. There was one hot spot that included the neighborhoods of Rodgers Park, Edgewater and West Ridge. These neighborhoods rank in the middle of Chicago’s crime rates and have lower poverty levels than the cold spot neighborhoods but are not the wealthiest neighborhoods within the city.
Figure 4.14. Rubella, Hybrid Model, 2003-2004 and Poverty in Chicago
Data Source: ESRI 2013a

The temporal changes between school years varied by vaccine, polio had the largest increase in both hot and cold spot schools. This finding follows the result from the General G
Statistic test that polio NMEs were much more clustered in 2013-2014 than in 2003-2004. The potential explanation for increased clustering of polio was discussed in that section.

There were a few notable differences between the hybrid and the 8nn model, the most obvious being the presence of cold spots in the hybrid data. To interpret the differences between models, it is necessary to discuss the benefits of both models. The strength of the 8NN model is that all schools are only compared to the nearest eight schools therefore ignoring potential effects of school density because the spatial area analyzed is based on the distance of the eight nearest neighbors, not a fixed distance. For the hybrid model, all schools within the specified area of 3,760.31 meters (2.3 miles) were assessed when determining the hot or cold spot classification. There were varying numbers of schools within 2.3 miles, resulting in higher density areas comparing many more schools than those in rural areas. For the 2003-2004 school year hybrid model, the average number of neighbors was 25.33 and the maximum was 137. Similarly, the 2013-2014 hybrid model had an average of 23.15 and a maximum of 123 schools. By not using a distance threshold, the 8NN model’s results will not be impacted by school or population density. This is important because a higher density in people can results in higher or lower incidence rates that is due to population density not due to an actual increase in phenomenon occurrence.

While the results of the hybrid model are influenced by school density, using a distance threshold for cluster detection is useful. In the occurrence of an outbreak or an epidemic, herd immunity throughout neighborhoods will be important to inhibit the spread of infectious disease. 2.3 miles is not a large area for people to travel and it is likely that a disease could easily traverse this distance. By only studying the eight nearest schools, clusters within dense areas could be overlooked because the study area is too small. Within Chicago there are
multiple instances where eight schools are located within just a few city blocks; in reality there is most likely interaction between these clusters because of the density of children and schools. The strength of the hybrid model is that it is more realistic in practice than the 8NN model.

Cold spots were only identified in urban areas for 2003-2004 and 2013-2014. No cold spot schools were identified using the 8NN model, meaning that in order to find a cold spot a density of more than eight schools is needed. Since the distance threshold parameter is necessary to identify cold spots, it is logical that there would not be any cold spots identified in rural areas where the hybrid model overrides the distance threshold to find the eight nearest neighbors. The identification of cold spots is an advantage of the hybrid model, even if they are only found in dense areas.

The density of schools contributes to finding hot spots as well. When comparing the models in both years studied, for every vaccine except polio in 2003-2004 there were more hot spots identified with the hybrid model. It is interesting that all vaccines besides polio in 2003-2004 had an increase between 43 and 50 additional hot spots for the hybrid model, while the polio 8NN model had one more school identified than the hybrid model. For some unknown reason school density did not have as much of an effect on polio exemptions in 2003-2004. This phenomenon was not present in the 2013-2014 school year, as the hybrid model identified 86 more hot spot schools than the 8NN model. The number of additional hot spot schools identified by the hybrid model in 2013-2014 was consistent across vaccines ranging between 84 to 90 additional schools.

For the rubella, varicella and mumps vaccines, the 8NN 2013-2014 test identifies a 10 school hot spot of varying confidence levels in the city of Peoria. The hybrid model does not identify any of these schools as hot spots; instead it identifies a four school cold spot (90 and
95% confidence). This phenomenon can be seen for the mumps vaccine in Figure 4.15. By using the hybrid parameter and including all schools within 2.3 miles, the 8NN hot spot disappears because the overall area has low exemption rates, essentially nullifying the higher exemption rates found in the hot spot schools. This example stresses the importance of different models, and the importance of selecting appropriate spatial weights as the maps in Figure 4.15 present two very different pictures. One of the goals of this thesis is to determine which methods are most appropriate to aid public health officials in quickly determining which areas to focus on in the event that low vaccination rate areas need to be identified. The benefit of conducting both the 8NN and the hybrid models is that the results can be easily compared and contradictory results can be identified (Figure 4.15). There are very few instances of conflicting results, making it more manageable to examine individual school percentages and determine what is really occurring in the location. Figure 4.16 shows that individual percentages of the Peoria schools, there are two schools with over 2.5% of students, Montessori School of Peoria with an exemption rate of 11% and Peoria Christian Academy with an exemption rate of 4.4%. These two schools have high enough exemption rates when compared with the eight nearest schools to create a hot spot. However, if examining the city of Peoria as a whole, exemption rates are low. Figure 4.16 shows that many schools within Peoria have zero children with religious exemptions which is why a cold spot is identified when examining more than the eight nearest schools.
Figure 4.15. Differences between 8NN and Hybrid Model in Peoria, 2013-2014 School Year

Figure 4.16. Percent of Students with Mumps Exemptions in Peoria, 2013-2014 School Year
Anselin Local Moran’s I Results

For the Anselin Local Moran’s I test, the results are reported in a z-score, p-value and cluster type. A high positive z-score indicates that neighboring school have similar values and denote a spatial cluster of either high or low values. Conversely, a low, negative z-score means that the school’s neighbors have either higher or lower NME rates. These schools are considered outliers. There are five potential classifications for a school, high-high cluster, low-low cluster, high-low outlier, low-high outlier and not significant. A high-high (HH) cluster is identified when there is a spatial cluster of high values, a low-low (LL) cluster when the exemption values are low. A high-low (HL) outlier occurs when a school with a high exemption rate is surrounded by low exemption rate schools, a low-high (LH) outlier occurs a low exemption school is located by high exemption rate schools. The full results of the tests are located in Tables 4.5 and 4.6. Appendix D contains state maps showing the results.

All vaccines for both models identified HH clusters and HL and LH outliers. No LL clusters were identified in any of the tests conducted. For all vaccines for both models, the number of HH clusters, HL and LH outliers were higher for the 2013-2014 school year. In general, the hybrid and 8NN models produced very similar results.

The remainder of this section discusses the results for the 2003-2004 school year, followed by the 2013-2014 results and concluding with the temporal differences between school years.
### Table 4.5. Anselin Local Moran’s I Results for the Eight Nearest Neighbor Parameter

<table>
<thead>
<tr>
<th>School Year</th>
<th>Cluster High-High</th>
<th>Outlier High-Low</th>
<th>Outlier Low-High</th>
<th>Cluster Low-Low</th>
<th>Not Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polio</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>37</td>
<td>13</td>
<td>6</td>
<td>0</td>
<td>5307</td>
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<tr>
<td>2013-2014</td>
<td>101</td>
<td>24</td>
<td>13</td>
<td>0</td>
<td>4743</td>
</tr>
<tr>
<td>Diptheria-Tetanus-Pertussis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>39</td>
<td>13</td>
<td>7</td>
<td>0</td>
<td>5304</td>
</tr>
<tr>
<td>2013-2014</td>
<td>90</td>
<td>31</td>
<td>14</td>
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<td>4746</td>
</tr>
<tr>
<td>Measles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>38</td>
<td>13</td>
<td>7</td>
<td>0</td>
<td>5305</td>
</tr>
<tr>
<td>2013-2014</td>
<td>101</td>
<td>39</td>
<td>21</td>
<td>0</td>
<td>4720</td>
</tr>
<tr>
<td>Mumps</td>
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<td></td>
<td></td>
<td></td>
</tr>
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<tr>
<td>2013-2014</td>
<td>95</td>
<td>28</td>
<td>17</td>
<td>0</td>
<td>4741</td>
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<tr>
<td>Rubella</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>32</td>
<td>12</td>
<td>7</td>
<td>0</td>
<td>5312</td>
</tr>
<tr>
<td>2013-2014</td>
<td>98</td>
<td>28</td>
<td>17</td>
<td>0</td>
<td>4738</td>
</tr>
<tr>
<td>Varicella (4,877 Schools)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2013-2014</td>
<td>84</td>
<td>27</td>
<td>20</td>
<td>0</td>
<td>4746</td>
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</tbody>
</table>

### Table 4.6. Anselin Local Moran’s I Results for the Hybrid Parameter.

<table>
<thead>
<tr>
<th>School Year</th>
<th>Cluster High-High</th>
<th>Outlier High-Low</th>
<th>Outlier Low-High</th>
<th>Cluster Low-Low</th>
<th>Not Significant</th>
</tr>
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<tr>
<td>Polio</td>
<td></td>
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<td></td>
<td></td>
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<td>2003-2004</td>
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<td>6</td>
<td>0</td>
<td>5302</td>
</tr>
<tr>
<td>2013-2014</td>
<td>116</td>
<td>39</td>
<td>14</td>
<td>0</td>
<td>4712</td>
</tr>
<tr>
<td>Diptheria-Tetanus-Pertussis</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>2003-2004</td>
<td>41</td>
<td>16</td>
<td>6</td>
<td>0</td>
<td>5300</td>
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<tr>
<td>2013-2014</td>
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<td>40</td>
<td>10</td>
<td>0</td>
<td>4717</td>
</tr>
<tr>
<td>Measles</td>
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<td></td>
<td></td>
</tr>
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<td>5296</td>
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<tr>
<td>2013-2014</td>
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<td>20</td>
<td>0</td>
<td>4699</td>
</tr>
<tr>
<td>Mumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>37</td>
<td>15</td>
<td>6</td>
<td>0</td>
<td>5305</td>
</tr>
<tr>
<td>2013-2014</td>
<td>107</td>
<td>32</td>
<td>11</td>
<td>0</td>
<td>4731</td>
</tr>
<tr>
<td>Rubella</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>37</td>
<td>15</td>
<td>6</td>
<td>0</td>
<td>5305</td>
</tr>
<tr>
<td>2013-2014</td>
<td>115</td>
<td>33</td>
<td>11</td>
<td>0</td>
<td>4722</td>
</tr>
<tr>
<td>Varicella (4,877 Schools)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013-2014</td>
<td>97</td>
<td>33</td>
<td>16</td>
<td>0</td>
<td>4731</td>
</tr>
</tbody>
</table>
The majority of schools for the 2003-2004 school year were not identified as part of a cluster or outlier. For the 8NN model, 0.95 to 1.1% of schools were classified as either HH, HL or LH depending on the vaccine tested. For the hybrid model, this range was 1.08 to 1.25% of schools. The 8NN model identified 32 (rubella) to 39 (DTP) HH clusters, 12 to 13 HL outliers and 6 to 7 LH outliers. The hybrid model identified 37 (mumps and rubella) to 43 (measles) HH clusters, 15 (mumps and rubella) to 18 (measles) HL outliers and 6 LH outliers. For every vaccine, there were more HH clusters and HL outliers identified by the hybrid model. The models identified very similar results for LH outliers; the 8NN model found one more school than the hybrid model for every vaccine except polio.

The locations for clusters and outliers for the 8NN and hybrid models are very similar. For the measles vaccine, both models identified HH clusters in the greater Chicago area, Bloomington, Carbondale and at the Southern tip of Illinois (Figure 4.17). HL Outliers are located in primarily urban areas within Chicago and surrounding suburbs, Rockford, Waukegan (hybrid only), and Peoria. In addition, there are two rural HL outliers located in the south central area of Illinois. For the hybrid model, LH outliers were only identified around Carbondale; the one addition school identified with the 8NN model is located in Forest Park, a Chicago suburb.
For the 2013-2014 school year, the number of clusters and outliers identified were still a very small percentage of the total number of schools. For the 8NN model, school identified as clusters of outliers ranged from 2.7% to 3.3%; for the hybrid model it ranged from 3.0% to 3.7%. For both models, varicella had the fewest number of schools and measles had the highest. The 8NN model identified 84 (varicella) to 101 (polio and measles) HH clusters. Both outlier categories had polio with the fewest and measles with the largest number of schools: HL outliers ranged from 24 to 39, LH outliers ranged from 13 to 21. The hybrid model identified more HH clusters for every vaccine, ranging from 97 (varicella) to 117 (measles). There were more HL outliers for every vaccine for the hybrid model as well, ranging from 32 (mumps) to 40 (DTP). The hybrid model had fewer LH outliers that the 8NN model for all vaccines except polio, ranging from 11 (mumps and rubella) to 20 (measles).
The locations of clusters and outliers for the 2013-2014 school year are located in both urban and rural areas. These locations are very similar when comparing the 8NN and hybrid models (Figure 4.18). For both models, measles HH clusters are located in urban areas throughout the Greater Chicago area, Rock Island, and Carbondale. Rural areas include northeast of Peoria, between Peoria and Bloomington, northeast of Springfield, southwest of Urbana and the southern tip of Illinois. The 8NN model identifies additional HH clusters in Peoria, Rockford and the greater Chicago area. HL outliers are located in multiple rural areas throughout the state with the majority within Chicago and surrounding suburbs. LH outliers are mainly in urban areas including Rock Island, Springfield and Chicago. The exception is three schools in Sidell, and three in Chrisman, rural towns southeast of Urbana. The hybrid model identifies additional outliers in Chicago and the western suburbs.
For both models, there was an increase in the number of clusters and outliers between the 2003-2004 and 2013-2014 school years, even though the total number of school for 2013-2014 is fewer than the 2003-2004 school year. For the 8NN model, HH clusters rose an average of 61.2 schools, HL outliers rose an average of 17.4 schools and LH outliers rose an average of 9.6 schools. For the 2003-2004 school year clusters and outliers were an average of 1.0% of total schools, for the 2013-2014 school year the average was 2.9% of schools. For the hybrid model the increase was slightly larger from 1.1% of schools in 2003-2004 to 3.3% in 2013-2014. Individually, HH clusters increased an average of 74.4 schools, HL outliers increase 21.8 schools and LH outliers increased 7.2 schools.

HH spatial clusters spread from predominately urban areas to urban and rural in 2013-2014. There were large increases in spatial clusters in the greater Chicago area. HH clusters appeared in Rockford and Peoria. In rural areas, HH clusters grew in the southern tip of Illinois and appeared throughout the center of the state (see Figures 4.17 and 4.18). HH clusters present in 2003-2004 in Bloomington and Carbondale were no longer classified as such in 2013-2014. The location of outliers also changed for the 2013-2014 school year. For the 8NN model, The HL outliers expanded throughout the great Chicago area, Belleville and Rockford. New locations include Rock Island, Springfield, Quincy and west of Chicago. New rural areas include north and south of Carbondale, southeast of Urbana, northeast of Springfield and north of Peoria. LH outliers appeared in Springfield, Rock Island, west of Chicago and southeast of Urbana. LH outliers west of Carbondale in 2003-2004 are no longer classified as outliers in 2013-2014. Outlier locations for the hybrid model as very similar to the 8NN model with the exception being more HL outliers in the Chicago suburbs. For more detail, Figures 4.19 and 4.20 shows all schools that contain at least one outlier.
Figure 4.19. Schools Containing At Least One Vaccine Exemption Outlier, 8NN Model

Figure 4.20. Schools Containing At Least One Vaccine Exemption Outlier, Hybrid Model
Anselin Local Moran’s I Discussion

The aforementioned results require temporal and spatial analysis to further understand exemption clusters and outliers in Illinois. Since the results to this test have many similarities to the Getis-Ord Gi* results, this discussion starts by comparing the results of these two tests. It then addressed outliers and their role in the vaccination exemption studies.

The results of the Anselin Local Moran’s I statistical tests are complementary to the Getis-Ord Gi* statistical test. Schools that are classified as HH clusters are also identified as hot spots (Figure 4.21). However, there are fewer HH schools than 99% confidence hot spot schools for all vaccines for both models. In addition, not all hot spots have HH cluster schools. For example, for the 2003-2004 school year, 8NN model, there is a polio hot spot in the city of Peoria and zero HH clusters (Figure 4.21). Similar to the Getis-Ord Gi* results, HH clusters spread to rural areas in the 2013-2014 test and appeared in many cities where there were new hot spots. HH clusters also disappeared from areas where hot spots also disappeared including Carbondale. Potential reasons why HH clusters appeared in these areas was previous addressed in the Getis-Ord Gi* discussion section. The increase in HH clusters for the 2013-2014 school year contributes to the idea that the polarity in vaccination exemptions is increasing within Illinois.

Although these tests use the same data and same parameters, the hot spot analysis can include schools with low exemption rates in a hot spot, as seen in the Peoria example in Figure 4.16. The Anselin Local Moran’s test requires HH clusters to have high exemption rates surrounded by other high exemption rates. By combining both test results, it is possible to identify which areas have the highest exemption rates and are at most risk for vaccine-preventable diseases.
Figure 4.21. Comparison of Anselin Local Moran’s I and Getis-Ord Gi* Results, Polio, 2003-2004, 8NN Model.

Figure 4.22. Comparison of Getis-Ord Gi* Results and Anselin Moran’s I Outliers, Chicago, Varicella, 2013-2014, Hybrid Model.
Anselin Local Moran’s I results did not identify any LL clusters. Since the HH clusters were located in Getis-Ord Gi* identified hot spots, it is interesting that there are no LL clusters in areas identified as cold spots. Interpreting the results of the Moran’s I test with the Getis-Ord Gi* test is necessary because without it, it could be assumed that there are no low exemption rate clusters. Areas with low exemption rates are most likely to have high levels of herd immunity and to be more protected from a vaccine-preventable disease outbreak. They are worthwhile to study to understand why these parents are more likely to vaccinate their children. Research results on why parents choose to vaccinate their children or why an area had such low vaccination exemption rates can contribute to public health vaccination initiatives.

Outliers are different that clusters in that they do not exhibit the similar exemption rates as nearby schools as specified in the parameters. Studying the outliers in context with the Getis-Ord Gi* results can be helpful as both HL and LH outliers appear in hot spot areas. For example, for the 2013-2014 hybrid model varicella results, two LH outliers were identified in the hot spot in the northern area of Chicago near Evanston (Figure 4.22). These schools contain low exemption rates but are still classified as a 99% hot spot because of the exemption rates of the neighboring schools. The HL outliers in this area include five schools within the large Chicago cold spot. The other eight HL outliers in Figure 4.22 are not part of a hot or cold spot.

The number of outliers increased for both models for all vaccines for the 2013-2014 school year. The increase in outliers also contributes to the narrative that the polarity of vaccination exemptions is growing. Notably, the average increase for HL outliers was more than the average increase for LH outliers for the 8NN model. For the hybrid model the average HL outliers increased three times more than the LH outliers. These increases indicate that it is
more common to find a high exemption rate school surrounded by low exemption rate schools than the opposite scenario.

The individual study of outliers can provide insight into reasons behind high or low exemption rates. Investigating why the outlier school does not exhibit the same trends as nearby schools could also shed light on parental motivations to procure vaccination exemptions. One such reason that an outlier has different exemption trends than nearby schools is that the outlier could draw a specific demographic to the school, such as a charter, magnet or private school. For the 13 HL outliers visible on Figure 4.22, eight are private schools, three in the suburbs and five within Chicago and two are charter schools, located within Chicago. The private schools are heterogeneous, including multiple faith-based schools (Christian, Catholic and Islamic), an independent school and approach-based schools (Montessori, Waldorf, International). Studying individual outliers is difficult, as each school has a unique situation that sets it apart from its neighbors.

Using the Getis-Ord Gi* results and the Anselin Local Moran’s I results together can provide a better understanding of where high NME schools are located. An example is the city of Springfield for 2013-2014 school year. All vaccines for both models of the Getis-Ord Gi* test identified a 99% confidence hot spot in Springfield; for the hybrid model, a 90% cold spot was identified in Springfield for all vaccines except varicella. All vaccines for both models of the Anselin Local Moran’s I identified both HL and LH outliers in Springfield, and the hybrid model identified one school as an HH clusters (Figure 4.23). The results of the Getis-Ord Gi* test show

17 These private schools located in the suburbs are: Word of God Christian Academy (Melrose Park), Our Lady Immaculate Academy (Oak Park), West Suburban Montessori School (Oak Park). Private schools located in Chicago are: Muhammad University of Islam, Urban Prairie Waldorf School, Providence St. Mel School, Midwestern Christian Academy and German International School Chicago.

18 The charter schools are Chicago Virtual Charter School and Academy for Global Citizenship.
that the city of Springfield has NME clusters divided into high exemption rates in the hot spot and low exemption rates in the small cold spot. Upon further analysis with the Anselin Local Moran's I results, it is evident that there is something unique going on within the city of Springfield and that the hot spot schools in this area should not be analyzed uniformly. The cold spot schools did not register as significant for the Anselin Local Moran’s I results. The one HH cluster signifies that there is a cluster of high NME rates within the areas. There are multiple outliers within the hot spot, including seven LH outliers and one HL outlier showing that the NME rates of the area are not homogenous. The high rate of LH outliers within the hot spot means that exemption rates must be very high in surrounding schools to create a 99% hot spot. To help further discover what is occurring in this area, Figure 4.23 shows the percent exempt for each schools in the area, emphasizing the heterogeneity in exemption rates within Springfield. There are multiple schools within the hot spot that have NME rates of zero including six of the seven LH outliers. The presence of an HL outlier within a 99% confidence hot spot indicates a very high exemption rate since it must be considerably higher than surrounding schools. This HL outlier is Grace Baptist Academy, a private school with an exemption rate of 50%. This exemption rate is concerning because it is way below herd immunity rates and deserves further scrutiny to understand why the NME rates are so high. The reason behind this high NME rate is low enrollment within the school (2 students). Grace Baptist Academy epitomizes one of the limitations to studying schools by exemption percentages instead of total number of students that have exemptions. While there are many advantages of studying exemption percentages, especially when using schools with diverse enrollment numbers, it can create situations where a small enrollment school has a large impact on a city, as has been discovered in Springfield.
Figure 4.23. Comparison of 2013-2014 DTP Hybrid Model in Springfield

By combining the results of these two tests, one can see that there are high NME rate clusters within Springfield, but the multiple outliers within the cluster show that the cluster contains both very high and low NME rates that deserve individualized analysis to understand what is occurring at these schools.

For the 2003-2004 school year, the hybrid model identified more HL outliers for every vaccine. However, the 8NN and hybrid model identified the same number of LH outliers for polio and one more cluster for every other vaccine. The increase in HL outliers with the hybrid model means that these outliers are more affected by the distance threshold than the eight nearest neighbors and identified in mainly urban areas (Figures 4.19 and 4.20). The similar numbers for the LH outliers indicate that most of these outliers are located in rural areas and thus unaffected by the hybrid model parameters. Most hot spots are located in urban areas for the 2003-2004 school year; it is unsurprising that LH outliers would be located in many rural areas since it would require multiple high exemption rate schools in order to create an outlier.
Summary

The three statistical tests presented in this chapter provide a way to identify clusters of both high and low nonmedical vaccination exemption rates in Illinois. Once identified, a temporal analysis was conducted to study NME rates and pattern trends between the 2003-2004 and 2013-2014 school years. Table 4.7 shows the average results for each test and model conducted. The General G statistical test proves that NME clusters are not a result of complete spatial randomness. The standard deviations increased, indicating more clustering for the 2013-2014 school year.

The Getis-Ord Gi* statistical test identified hot and cold spots throughout Illinois. This test locates clusters schools that have either higher or lower than expected exemption rates. However, not all schools within the cluster have the labelled exemption characteristics. For example, if a school has a low exemption rate but is surrounded by high exemption rate schools, it could be identified as a hot spot. The strength of the Getis-Ord Gi* test is that it easily identifies clusters of high and low NME rates, providing a starting point for in depth analysis. In the event of a vaccine-preventable outbreak, hot spot locations could aid public health personnel. In addition, the Getis-Ord Gi* results can be interpreted over time, as hot and cold spots shift and grow. The increase in both hot and cold spots for this thesis provide evidence that the polarity in vaccination exemption decisions is growing.
Table 4.7. Results Summary

<table>
<thead>
<tr>
<th>Statistical Test</th>
<th>School Year</th>
<th>Model</th>
<th>Vaccines</th>
<th>Results</th>
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<td>Getis-Ord General G</td>
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<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
<td>High Spatial Clustering</td>
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<td>Getis-Ord General G</td>
<td>2013-2014</td>
<td>8NN, Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
<td>High Spatial Clustering</td>
</tr>
<tr>
<td>Getis Ord-Gi*</td>
<td>2003-2004</td>
<td>8NN</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
<td>Average 198.8 Hot Spot Schools</td>
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<td>Getis Ord-Gi*</td>
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<td>Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
<td>Average 236.4 Hot Spot &amp; 59.2 Cold Spot Schools</td>
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<td>Getis Ord-Gi*</td>
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<td>8NN</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
<td>Average 432.2 Hot Spot Schools</td>
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<td>Getis Ord-Gi*</td>
<td>2013-2014</td>
<td>Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
<td>Average 518.5 Hot Spot &amp; 516.8 Cold Spot Schools</td>
</tr>
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<td>Aneslin Local Moran's I</td>
<td>2003-2004</td>
<td>8NN</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
<td>Average 35.8 HH Cluster, 12.6 HL Outlier, 6.8 LH Outlier Schools</td>
</tr>
<tr>
<td>Aneslin Local Moran's I</td>
<td>2003-2004</td>
<td>Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella</td>
<td>Average 39.4 HH Cluster, 16 HL Outlier, 6 LH Outlier Schools</td>
</tr>
<tr>
<td>Aneslin Local Moran's I</td>
<td>2013-2014</td>
<td>8NN</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
<td>Average 94.8 HH Cluster, 29.5 HL Outlier, 17 LH Outlier Schools</td>
</tr>
<tr>
<td>Aneslin Local Moran's I</td>
<td>2013-2014</td>
<td>Hybrid</td>
<td>Polio, DTP, Measles, Mumps, Rubella, Varicella</td>
<td>Average 111 HH Cluster, 37 HL Outlier, 13.7 LH Outlier Schools</td>
</tr>
</tbody>
</table>
Figure 4.24. 99% Confidence Hot Spot Schools for all Vaccines, 8NN and Hybrid Models
There were 83 schools for the 2013-2014 school year that were classified as 99% confidence hot spots for both the 8NN and they hybrid models for al vaccines (Figure 4.24). These schools should be investigated further, especially to determine if the herd immunity threshold is at risk. These hot spot schools are dispersed throughout the state, with a large proportion in the wealthier, western Chicago suburbs. Not all schools are in the wealthiest census tracts, however; most are in areas where the median household income is above $39,000. Multiple schools are in more rural areas with less population density, showing that high exemption rates are not limited to population-dense areas. A complete list of the 83 schools is located in Appendix E. Interestingly, of the 83 school, none were charter or magnet schools and 21 were private schools (25.3%). For perspective, private schools made up 20.8% of the total number of schools for the 2013-2014 school year, so this number is slightly higher than the expected amount of private schools. Magnet schools were 2.2% and charter were 1.1% of total schools, so the absence of them from this list is unsurprising.

The Anselin Local Moran’s I test further aids in understanding the exemption rates with the hot and cold spots by classifying schools as clusters or outliers. This additional detail is useful; the HH clusters are more selective that hot spots, as they require multiple high exemption rate schools and therefore these clusters provide a definitive location of high NME clusters. Outliers indicate a unique situation where a school has a different exemption pattern than the surrounding schools. The presence of outliers within hot or cold spots can help understand what is occurring within the area. For example, for the large cold spot located in Chicago there are multiple HL outliers. The exemption rates within this cluster is so low that it overrides the higher exemption rate in the outlier school. The Anselin Local Moran’s I best functions as a complementary test to the Getis-Ord Gi*; interpreting the results without the
Getis-Ord Gi* context is difficult and does not provide a full picture of NME trends within Illinois. The number of HH clusters is much smaller than the hot spot results, if one only used the HH clusters, many schools with higher NME rates would be missing from the analysis. The outliers are unique situations making it difficult to draw conclusions that unify them together. Individually studying outliers is time consuming which could deter analysis. In addition, it is more difficult to identify temporal trends using the clusters and outliers because of the small number of school classified as such. However, the increase of HH clusters and of outliers for the 2013-2014 school year further proving that vaccination exemption polarity is growing. Together the Getis-Ord Gi* and the Anselin Local Moran’s I provide the ability to quickly identify hot and cold spots for NME rates while also providing detail and context. Both tests are crucial in the identification of high and low NME clusters.
Conclusion

Studying vaccination and vaccination exemption rates within the United States requires analysis at multiple scales. The lack of federal-level laws creates a heterogeneous landscape with many different policies and data collection procedures. Each state has different methods of collecting, storing and reporting vaccination data to the CDC, creating many challenges for conducting an in-depth comparison between different states. Investigating vaccination at the state level can provide insight as to the effectiveness of current vaccination policies as well as provide an overview of vaccination levels. Local-scale analysis is important to determine which areas have lower vaccination rates and are at greater risk for vaccine-preventable outbreaks.

Anti-vaccination sentiments have been present in the United States since the introduction of compulsory vaccination. Many of the tactics used by current anti-vaccination activists are similar to those used in the late nineteenth and early twentieth centuries. The momentum for the current anti-vaccination movement stems from a PBS documentary aired in 1982. Vaccination exemptions have historically accompanied vaccination laws; current nonmedical exemption policies are constantly evolving within each state. Since 1991 NME rates have increased throughout the United States (Omer et al. 2006; Omer et al. 2012). Research has identified geographical clusters of NMEs creating areas with low vaccination rates that present risks to community herd immunity levels (May and Silverman 2003; Omer et al. 2008).

The state of Illinois provides opportunities to study temporal changes in vaccination exemptions in a culturally, demographically and geographically diverse population. The Illinois State Board of Education collects and maintains vaccination data for each school, by vaccine.
This data is publicly available on their website starting with the 2003-2004 school year. This school year and the 2013-2014 school year were used for statistical tests to identify if NMEs clustered and where these clusters were located within Illinois. Using two different parameters, one including the eight nearest neighbors and the other a hybrid of a distance threshold or a minimum of eight nearest neighbors, this thesis conducted three statistical tests on the data.

The Getis-Ord General G statistical test identified that vaccination exemptions are highly clustered and rejected the hypothesis of complete spatial randomness. The Getis-Ord Gi* test identified hot and cold spots primarily in high population density areas for 2003-2004 with hot spots spreading to lower density areas of varying income level for 2013-2014. The 8NN tests only identified hot spots, the hybrid tests identified both hot and cold spots. Each test and parameter resulted in some vaccine spatial variability, stressing the importance of studying individual vaccines, not just vaccination rates as an entirety. There were more hot and cold spots identified for the 2013-2014 school year. The hybrid model best shows the polarity of vaccination exemptions as the number of hot and cold spots increased, whereas the 8NN model best ignores potential effects of school density because the spatial area analyzed is based on the distance of the eight nearest neighbors, not a fixed distance. The Anselin Local Moran’s I test shows clusters and outliers and can provide insight into what is occurring within a hot spot. The Anselin Local Moran’s I test is complementary to the Getis-Ord Gi* test; it is difficult to interpret the results of this test without hot spot identification. Each outlier presents a unique situation worthy of investigation to help identify what is occurring within these schools and their surrounding neighbors. The Anselin Local Moran’s I test identified the increase in HH clusters, LH and HL outliers for the 2013-2014 school year, providing evidence that more parents are choosing vaccination exemptions.
The models presented in this thesis were designed to create an accessible way to detect areas with lower vaccination rates. Studying schools individually is time-intensive and impractical in the event of an outbreak or epidemic. Hot spots and HH clusters quickly identify areas that require in depth analysis. Through the use of both a hybrid model that incorporates a distance threshold and a minimum nearest neighbors and a pure k-nearest neighbors model, this thesis shows how different spatial weights produce different results that could impact public health planning. By conducting both of these models, this thesis was able to identify areas with contradictory results and the “hottest” schools within Illinois that tested 99% confidence on all models and vaccines for the 2013-2014 school year (Figure 4.24). It is recommended that public health officials start with the Getis-Ord Gi* hot spot test, followed by the Anselin local Moran’s for a more detailed analysis.

Some of the limitations to this thesis are not easily solvable; for example, the MAUP and edge effects will occur in the majority of spatial studies. Federally, the heterogeneous data collection methods and reporting procedures from individual states to the CDC creates unnecessary barriers to studying vaccination and exemptions. The CDC already has standards in place, but there is no incentive or punishment for states that do not comply. The National Program of Cancer Registries, a CDC-run, very effective tracking mechanism of cancer incidences, should be used as an example to set up a federal-level vaccination database. This program has effective data quality standards allowing for multi-state research and a has resulted in a proliferation of publications and research (CDC 2016c).

Data limitations specific to this thesis could be improved upon for future research. There were small errors in the vaccination data consolidated by ISBE and schools that failed to report were missing from the data. School districts that do not report vaccination data to the
state do not receive a portion of their state funding. The ISBE could reject incorrectly reported vaccination data forcing school districts to report correctly to receive credit and therefore be eligible for all of their state funding. The ISBE could also require school districts to report by grade level so that data on vaccines required for only certain ages such as HiB and hepatitis B would accurately reflect the required number of students instead of the entire student population. By tracking vaccination data at the grade level instead of the entire school it would be easier to see age cohorts within the system. Illinois could also require homeschooling parents to report vaccination status even though these children are not required to be vaccinated. By including homeschooled children, Illinois would have vaccination records for all school-aged children. Another recommendation is that ISBE should maintain geocoded vaccination data so that vaccination and vaccination exemption spatial patterns can be more easily studied. The process to geocode vaccination data is time consuming and subject to human error. If ISBE adds geographic coordinates to the vaccination data, it would enhance the capabilities for spatial analysis.

This thesis creates many opportunities for future work on nonmedical exemption rate and clusters. In August 2015, Illinois amended current vaccination exemption law, requiring parents who seek a vaccination exemption to have a health provider’s signature in addition to a personal exemption statement starting with the 2016-2017 school year. ISBE defines a health care provider as “physicians licensed to practice medicine in all of its branches, advanced practice nurses, or physician assistants” (ISBE 2015). This additional requirement makes an exemption more difficult to procure, changing Illinois’ exemption requirement from “medium” to “difficult” on Rota’s exemption difficulty scale (2001). Other studies have shown that when a state changes difficulty level, the number of NMEs decrease and that “difficult” states have
lower numbers of NMEs compared to “medium’ states (Rota et al. 2001; Omer et al. 2012; Bradford and Mandich 2015). The change in exemption laws provides a landscape primed for future work which could include changes the overall NME rates and the location and proportion of hot and colds spots within the state. In addition to studying NME rates, future work could also include medical exemptions to see if the increase in difficulty persuades parents to procure medical exemptions. In 2009 Washington State altered exemption laws to include a health care provider’s signature. By 2012 the NME rates decreased 30% but the medical exemptions increased 253% (Bradford and Mandich 2015).

Continued analysis of this data could incorporate identified hot spots and herd immunity thresholds. Identifying schools or clusters where herd immunity is in danger or at a certain risk threshold and creating maps showcasing this information would be valuable to parents and public health officials. Other future work could involve different spatial statistical tests or conducting the Getis-Ord Gi* and Anselin Local Moran’s I tests with different parameters or with using the total number of students exempt instead or the percent exempt. To address the schools with small enrollment numbers, a minimum enrollment threshold could be used to remove these schools from results. Minnesota does not report vaccination data for schools with less than ten students and Iowa does not report data for schools with less than 100 students (Minnesota Department of Health 2015; Iowa Department of Public Health 2016). Examining the temporal changes between public and private schools could also yield interesting results as previous research has shown that private schools tend to have higher exemption rates(Salmon, Omer, et al. 2005; Carrel and Bitterman 2015). Lastly, the methods presented in this thesis could be applied to other states that maintain school-level vaccination data.
Spatial analysis at multiple scales is important to comprehend the complexity of vaccination exemptions. Studies conducted at the state-level or smaller provide insight into exemption patterns and trends over time. In the event of a vaccine-preventable infectious disease outbreak, knowing which communities have more vulnerable populations aids in outbreak containment and control. Nonmedical vaccination rates in Illinois are rising and the increase in hot and cold spots is evidence that the polarity of vaccination choices is increasing. As vaccination exemption rates continue to polarize American society, it is essential for public health efforts to monitor and conduct local-levels studies.
Appendix A

Spatial Autocorrelation Calculations

To obtain the distance threshold that would find maximum cluster, ArcMap’s Incremental Spatial Autocorrelation tool was used (ESRI 2014). This tool measures spatial autocorrelation for a series of distances and identifies statistically significant peak z-scores that indicate distances where clustering is most pronounced (ESRI 2016e). Since the goal of identifying a distance threshold is to further identify clusters in urban areas, the densest area of data was chosen for this calculations. As a result, the data input for this calculation was any school with an address within the City of Chicago within the 2003-2004 database, totaling 776 schools out of the 5,363 schools in the database. The category of percent polio exempt was used as the input field. The default settings of 10 distance bands and row standardization were selected for this calculation. Figure A.1 is the line graph produced by ArcMap identifying two peak z scores, 2064.10 meters and 3760.31 meters. This indicates that there are two distances where clustering is pronounced. Since the scale of analysis for this thesis includes urban and rural areas, the 3760.31-meter distance was chosen as the distance threshold parameter. In addition, the 3760.31-meter distance has a lower p-value indicating that this distance is more statistically significant (see Table A.1).
Figure A.1. Incremental Spatial Autocorrelation Distance Graph

Table A.1 Incremental Spatial Autocorrelation Z-score and P-value

<table>
<thead>
<tr>
<th>Distance</th>
<th>Moran's I</th>
<th>Expected Index</th>
<th>Variance</th>
<th>z-score</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1640.05</td>
<td>0.016680</td>
<td>-0.001290</td>
<td>0.000145</td>
<td>1.890740</td>
<td>0.136030</td>
</tr>
<tr>
<td>2064.10</td>
<td>0.015103</td>
<td>-0.001290</td>
<td>0.000091</td>
<td>1.718393</td>
<td>0.085725</td>
</tr>
<tr>
<td>2488.15</td>
<td>0.008509</td>
<td>-0.001290</td>
<td>0.000063</td>
<td>1.230362</td>
<td>0.218562</td>
</tr>
<tr>
<td>3122.21</td>
<td>0.001387</td>
<td>-0.001290</td>
<td>0.000047</td>
<td>1.847568</td>
<td>0.066665</td>
</tr>
<tr>
<td>3336.26</td>
<td>0.016693</td>
<td>-0.001290</td>
<td>0.000036</td>
<td>3.099711</td>
<td>0.002615</td>
</tr>
<tr>
<td>3760.31</td>
<td>0.018422</td>
<td>-0.001290</td>
<td>0.000028</td>
<td>3.740877</td>
<td>0.000183</td>
</tr>
<tr>
<td>4184.36</td>
<td>0.014834</td>
<td>-0.001290</td>
<td>0.000022</td>
<td>3.417456</td>
<td>0.000632</td>
</tr>
<tr>
<td>4608.41</td>
<td>0.012563</td>
<td>-0.001290</td>
<td>0.000018</td>
<td>3.225154</td>
<td>0.000129</td>
</tr>
<tr>
<td>5032.46</td>
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<td>-0.001290</td>
<td>0.000015</td>
<td>3.608543</td>
<td>0.000308</td>
</tr>
<tr>
<td>5456.51</td>
<td>0.009990</td>
<td>-0.001290</td>
<td>0.000013</td>
<td>3.124211</td>
<td>0.000783</td>
</tr>
</tbody>
</table>

First Peak (Distance, Value): 2064.10, 1.718393
Max Peak (Distance, Value): 3760.31, 3.740877
Distance measured in Meters
Appendix B

State-Level Hot and Cold Spot Maps

This Appendix contains maps of hot and cold spots for the entire state of Illinois. The maps are presented in temporal comparison starting with the 8NN model and then followed by the hybrid model.

Figure B.1. Getis-Ord Gi* Results, DTP, 8NN Model
Figure B.2. Getis-Ord Gi* Results, Measles, 8NN Model

Figure B.3. Getis-Ord Gi* Results, Mumps, 8NN Model
Figure B.4. Getis-Ord Gi* Results, Polio, 8NN Model

Figure B.5. Getis-Ord Gi* Results, Rubella, 8NN Model
Figure B.6. Getis-Ord Gi* Results, Varicella, 8NN and Hybrid Models

Figure B.7. Getis-Ord Gi* Results, DTP, Hybrid Model
Figure B.8. Getis-Ord Gi* Results, Measles, Hybrid Model

Figure B.9. Getis-Ord Gi* Results, Mumps, Hybrid Model
Figure B.10. Getis-Ord Gi* Results, Polio, Hybrid Model

Figure B.11. Getis-Ord Gi* Results, Rubella, Hybrid Model
Appendix C

Chicago Hot and Cold Spot Maps

This Appendix contains maps of hot and cold spots within the city of Chicago. The maps are presented in temporal comparison starting with the 8NN model and then followed by the hybrid model.

Figure C.1. Getis-Ord Gi* Results, DTP, 8NN Model
Figure C.2. Getis-Ord Gi* Results, Measles, 8NN Model

Figure C.3. Getis-Ord Gi* Results, Mumps, 8NN Model
Figure C.4. Getis-Ord Gi* Results, Polio, 8NN Model

Figure C.5. Getis-Ord Gi* Results, Rubella, 8NN Model
Figure C.6. Getis-Ord Gi* Results, Varicella, 8NN Model on right, hybrid Model on left

Figure C.7. Getis-Ord Gi* Results, DTP, Hybrid Model
Figure C.8. Getis-Ord $G_i^*$ Results, Measles, Hybrid Model

Figure C.9. Getis-Ord $G_i^*$ Results, Mumps, Hybrid Model
Figure C.10. Getis-Ord Gi* Results, Polio, Hybrid Model

Figure C.11. Getis-Ord Gi* Results, Rubella, Hybrid Model
Appendix D

State-Level Cluster and Outlier Maps

This Appendix contains the results from the Anselin Local Moran’s I test for the entire state of Illinois. The maps are presented in temporal comparison starting with the 8NN model and then followed by the hybrid model.

Figure D.1. Anselin Local Moran’s I Results, DTP, 8NN Model
Figure D.2. Anselin Local Moran’s I Results, Measles, 8NN Model

Figure D.3. Anselin Local Moran’s I Results, Mumps, 8NN Model
Figure D.4. Anselin Local Moran’s I Results, Polio, 8NN Model

Figure D.5. Anselin Local Moran’s I Results, Rubella, 8NN Model
Figure D.6. Anselin Local Moran’s I Results, Varicella, 8NN and Hybrid Models

Figure D.7. Anselin Local Moran’s I Results, DTP, Hybrid Model
Figure D.8. Anselin Local Moran's I Results, Measles, Hybrid Model

Figure D.9. Anselin Local Moran's I Results, Mumps, Hybrid Model
Figure D.10. Anselin Local Moran’s I Results, Polio, Hybrid Model

Figure D.11. Anselin Local Moran’s I Results, Rubella, Hybrid Model
Appendix E

99% Confidence Hot Spot Schools

This Appendix lists all schools that were classified as 99% Confidence Hot Spot Schools for all vaccines for both the 8NN and the hybrid models for the 2013-2014 school year. Figure 4.23 is a map showing the locations.

Table E.1. List of 99% Confidence Hot Spot Schools for All Vaccines, 8NN and Hybrid Models

<table>
<thead>
<tr>
<th>School Name</th>
<th>City</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNA MCDONALD ELEMENTARY SCHOOL</td>
<td>MANHATTAN</td>
<td>Public</td>
</tr>
<tr>
<td>BENJAMIN FRANKLIN MIDDLE SCHOOL</td>
<td>SPRINGFIELD</td>
<td>Public</td>
</tr>
<tr>
<td>BLACK HAWK ELEMENTARY SCHOOL</td>
<td>SPRINGFIELD</td>
<td>Public</td>
</tr>
<tr>
<td>BLESSED SACRAMENT</td>
<td>SPRINGFIELD</td>
<td>Private</td>
</tr>
<tr>
<td>BUTLER ELEMENTARY SCHOOL</td>
<td>SPRINGFIELD</td>
<td>Public</td>
</tr>
<tr>
<td>CALEDONIA CHRISTIAN ACADEMY</td>
<td>OLMSTED</td>
<td>Private</td>
</tr>
<tr>
<td>CALVARY BAPTIST ACADEMY</td>
<td>CHILLCOTHE</td>
<td>Private</td>
</tr>
<tr>
<td>CENTURY ELEMENTARY SCHOOL</td>
<td>ULLIN</td>
<td>Public</td>
</tr>
<tr>
<td>CENTURY JR/SR HIGH SCHOOL</td>
<td>ULLIN</td>
<td>Public</td>
</tr>
<tr>
<td>CHRISMAN ELEMENTARY SCHOOL</td>
<td>CHRISMAN</td>
<td>Public</td>
</tr>
<tr>
<td>CHRISMAN HIGH SCHOOL</td>
<td>CHRISMAN</td>
<td>Public</td>
</tr>
<tr>
<td>CHRISMAN-SCOTTLAND JR HIGH SCHOOL</td>
<td>CHRISMAN</td>
<td>Public</td>
</tr>
<tr>
<td>CHRIST THE KING ELEMENTARY SCHOOL</td>
<td>SPRINGFIELD</td>
<td>Private</td>
</tr>
<tr>
<td>CHURCHILL ELEMENTARY SCHOOL</td>
<td>GLEN ELLYN</td>
<td>Public</td>
</tr>
<tr>
<td>CIRCLE CENTER GRADE SCHOOL</td>
<td>YORKVILLE</td>
<td>Public</td>
</tr>
<tr>
<td>CLAPHAM SCHOOL</td>
<td>WHEATON</td>
<td>Private</td>
</tr>
<tr>
<td>CLINTON ELEMENTARY SCHOOL</td>
<td>CHICAGO</td>
<td>Public</td>
</tr>
<tr>
<td>CORRON ELEMENTARY SCHOOL</td>
<td>SOUTH ELGIN</td>
<td>Public</td>
</tr>
<tr>
<td>CROSS EV LUTHERAN SCHOOL</td>
<td>YORKVILLE</td>
<td>Private</td>
</tr>
<tr>
<td>DA VINCI ACADEMY</td>
<td>ELGIN</td>
<td>Private</td>
</tr>
<tr>
<td>EARLY LEARNING CENTER</td>
<td>SPRINGFIELD</td>
<td>Public</td>
</tr>
<tr>
<td>EDGEEWOOD GRADE SCHOOL</td>
<td>EDGEEWOOD</td>
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</tr>
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<td>EDISON MIDDLE SCHOOL</td>
<td>WHEATON</td>
<td>Public</td>
</tr>
<tr>
<td>School Name</td>
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<td>Type</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>---------------</td>
<td>---------</td>
</tr>
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<td>Edwin A Lee Elementary School</td>
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</tr>
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<td>Moline</td>
<td>Public</td>
</tr>
<tr>
<td>Ferson Creek School</td>
<td>St Charles</td>
<td>Public</td>
</tr>
<tr>
<td>Fox Meadow Elementary School</td>
<td>South Elgin</td>
<td>Public</td>
</tr>
<tr>
<td>Franklin Middle School</td>
<td>Wheaton</td>
<td>Public</td>
</tr>
<tr>
<td>Georgetown-Ridge Farm High School</td>
<td>Georgetown</td>
<td>Public</td>
</tr>
<tr>
<td>Glenbard West High School</td>
<td>Glen Ellyn</td>
<td>Public</td>
</tr>
<tr>
<td>Grace Baptist Academy</td>
<td>Springfield</td>
<td>Private</td>
</tr>
<tr>
<td>Hadley Junior High School</td>
<td>Glen Ellyn</td>
<td>Public</td>
</tr>
<tr>
<td>Hanna Sacks BaasYaakov High School</td>
<td>Chicago</td>
<td>Private</td>
</tr>
<tr>
<td>Harvard Park Elementary School</td>
<td>Springfield</td>
<td>Public</td>
</tr>
<tr>
<td>Hawthorne Elementary School</td>
<td>Wheaton</td>
<td>Public</td>
</tr>
<tr>
<td>Hayt Elementary School</td>
<td>Chicago</td>
<td>Public</td>
</tr>
<tr>
<td>Il Valley Central High School</td>
<td>Chillicothe</td>
<td>Public</td>
</tr>
<tr>
<td>Jamaica Elementary School</td>
<td>Sidell</td>
<td>Public</td>
</tr>
<tr>
<td>Jamaica High School</td>
<td>Sidell</td>
<td>Public</td>
</tr>
<tr>
<td>Jamaica Jr High School</td>
<td>Sidell</td>
<td>Public</td>
</tr>
<tr>
<td>Kilmer Elementary School</td>
<td>Chicago</td>
<td>Public</td>
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<tr>
<td>Lincoln Elementary School</td>
<td>Wheaton</td>
<td>Public</td>
</tr>
<tr>
<td>Living Hope Fellowship Christian School</td>
<td>Karnak</td>
<td>Private</td>
</tr>
<tr>
<td>Longfellow Elementary School</td>
<td>Wheaton</td>
<td>Public</td>
</tr>
<tr>
<td>Lowell Elementary School</td>
<td>Wheaton</td>
<td>Public</td>
</tr>
<tr>
<td>Lubavitch Girls High School</td>
<td>Chicago</td>
<td>Private</td>
</tr>
<tr>
<td>Mary Miller Junior High School</td>
<td>Georgetown</td>
<td>Public</td>
</tr>
<tr>
<td>Meridian Elementary School</td>
<td>Mounds</td>
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</tr>
<tr>
<td>Meridian High School</td>
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<tr>
<td>New Field Elementary School</td>
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</tr>
<tr>
<td>Northside Catholic Academy</td>
<td>Chicago</td>
<td>Private</td>
</tr>
<tr>
<td>Notre Dame De La Salette</td>
<td>Georgetown</td>
<td>Private</td>
</tr>
<tr>
<td>Otter Creek Elementary School</td>
<td>Elgin</td>
<td>Public</td>
</tr>
<tr>
<td>Parkview Christian Academy</td>
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<td>Peaceful Pathways Montessori</td>
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</tr>
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<td>Pine Crest Elementary School</td>
<td>Georgetown</td>
<td>Public</td>
</tr>
<tr>
<td>Prairie Knolls Middle School</td>
<td>Elgin</td>
<td>Public</td>
</tr>
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<td>Prairie View Grade School</td>
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<td>Sandburg Elementary School</td>
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