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ORIGINAL RESEARCH ARTICLE

A Prediction Model of Childhood Immunization Rates

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Abstract

Background This research begins by providing background on the status and literature of childhood immunization in the USA. Vaccine-preventable diseases have been on the rise in Europe and the USA in the last few years. Cases of measles and pertussis have all been increasing at alarming rates. The article begins with a discussion of the use of immunization exemptions across the states and a brief history of US immunization policy. A review of the literature confirms that socioeconomic status and other demographic characteristics can be important predictors of childhood vaccine uptake.

Aim Given the seriousness of this public health issue, the primary objective of this research is to analyze the determinants of a child in the USA being fully vaccinated.

Methods A range of socioeconomic and demographic characteristics, along with data from the National Immunization Survey, are used to develop an immunization prediction model. Logistic regression is the chosen method in determining whether a preschool-age child in the USA today is likely to be vaccinated based on various demographic and socioeconomic characteristics.

Results Model results reveal a number of significant socioeconomic and demographic characteristics that contribute to the likelihood of a child being immunized. The overall logistic regression model was highly significant at the 5 % level and model parameters are significant. Significant variables in the model include categories of educational attainment, first born child, race and ethnicity, age of mother, and census region. This model does not definitively reveal that later born children are less likely to get fully vaccinated than first born children but does confirm the significance of geography in immunization outcomes. All levels of education were found to be significant along with all census regions.

Conclusions Overall, these models reveal that demographic and socioeconomic characteristics are predictors of childhood immunization and if leveraged appropriately can assist policy makers and public health officials to understand immunization rates and craft policy to improve them.

Key Points for Decision Makers

Demographic and socioeconomic characteristics are determinants of childhood immunization rates.

Targeted policy efforts could improve immunization rates among specific groups.

A multi-pronged policy approach focusing on both the demand and supply of immunization could improve immunization access and rates among groups.

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1 Introduction

Immunization has historically been a key component of healthcare for children in the USA, but the cultural consensus that immunization is good for children has been eroding. Two critical factors contributing to this erosion are: (1) Many families are no longer personally acquainted with the mortality of immunization-preventable diseases; and (2) Certain organizations have publicized potential negative health consequences of immunization for young children. In fact, child immunization rates plummeted in parts of Europe and the UK after a 1998 study falsely claimed that the vaccine for measles, mumps and rubella was linked to autism [1]. With this trend, immunization rates in the USA among preschool-age children have been falling as evidenced by the outbreak of vaccine-preventable diseases across the country for the last five years [2]. It has been estimated that nearly 30 % of 2-year-olds in the USA are not fully immunized against deadly childhood diseases such as measles, polio, mumps, rubella, tetanus, and whooping cough [3]. In areas with low vaccination rates, epidemics are of increasing concern. Epidemics, such as the 1989 measles epidemic, occurred in areas of the country where the percentage of fully vaccinated children is as low as 17 % [4].

The USA has seen an alarming increase in the rate of vaccine-preventable disease over the last several years [5]. This phenomenon has been most noticeable with measles but has also included other diseases, like pertussis, also known as whooping cough, in growing numbers. Twenty-three states, from January to May, 2011, reported the highest number of measles cases, for the same period, since 1996 [4]. Pertussis, once thought to be largely eliminated in the USA, has also seen a resurgence. In 2010, a pertussis outbreak in California led to 455 infants being hospitalized and 10 deaths [6, 7]. Pertussis cases have been reappearing at record levels, with 2012 experiencing over 41,000 infections and an estimated 18 deaths in the USA [8]. These dramatic increases in vaccine-preventable diseases have led healthcare professionals and policy makers to examine the reasons behind these shifts.

Such outbreaks have led to concern about the number of families forgoing vaccination [9]. Increasing rates of nonmedical exemptions from school immunization programs are a key contributor in the rise of vaccine-preventable diseases [9]. From 1991–2004, the mean state level of nonmedical exemption increased from 0.98 to 1.48 %. This rate of increase is not what concerns policy makers the most; it is the clustering of communities around the nation that have higher levels of exemptions compared to the state and national average [10]. Ashland, Oregon, as one example, has an 11 % rate of nonmedical exemption, compared to 2.7 % for the entire state of Oregon [11]. The primary concern with the rise in nonmedical exemptions is the increased probability that herd immunity is eliminated or greatly reduced across these communities.

While states have different policies on exemptions, every state except two allow religious exemptions and 17 states allow for "personal belief" exemptions [12, 13]. Additionally, states vary in their leniency concerning the process and documentation required for an exemption. In 23 states, school officials cannot refuse an exemption if the request fulfills basic state requirements [14]. Several states do not have specific procedures for filing exemptions and some that do not allow for specific types of exemptions appear to have students in their school systems with these exemptions [15]. This varied and confusing policy landscape is argued to be a contributing factor to the increase in disease outbreaks across the USA. Some states are responding to these outbreaks with new legislation to restrict exemptions. Recently, lawmakers in Oregon and Washington have passed laws increasing the difficulty of receiving nonmedical exemptions for kindergarten vaccinations [16].

This study explores some of the underlying variables that influence a family's choice to immunize their children in 2007. Using data from the National Immunization Survey, we developed a prediction model to determine whether a preschool-age child is fully vaccinated given a range of different demographic and socioeconomic variables. In addition, this research explores policy measures that could increase childhood immunization rates and future research efforts that could improve our understanding of patterns of immunization uptake behaviors.

2 Theoretical Background

From a policy perspective, the fact that immunizations are considered a merit good—having both public (non-rival and non-excludable) and private (excludable and rival) good characteristics—has a large impact on how it is argued they should be financed and delivered to society [17]. Merit goods are often produced under the socially optimal quantity. To reach this socially optimal quantity requires economic incentives for research and development, as the social and economic spillover effects from having a healthier and longer-living population are substantive. Given this, if society values vaccination for children across the country, a concerted public policy effort is needed.

Experts in the field of health have very little disagreement about the benefits of immunization. This is true even despite the recent public exposure to the "dangers" of immunizations by celebrities such as Jenny McCarthy. These recent campaigns have only served to weaken demand for vaccination. Media coverage has increased

concern over the side effects of immunization, which has led to decreases in vaccination coverage rates, especially in the USA and Sweden [18].

Fundamental cause theory has more recently been used as one way to explore potential healthcare disparities across populations, including immunizations. Phelan et al. [19] argue that health disparities remain because of "an array of resources, such as money, knowledge, prestige, power, and beneficial social connections that protect health no matter what mechanisms are relevant at any given time". New healthcare approaches have been the focus of fundamental cause theory. However, the central theme of the influence of social conditions on how healthcare advances become common practice is relevant for this research [20].

With regard to childhood immunization practice, it is difficult to argue that these are novel health innovations today. However, one might have argued twenty years ago that immunization was a fully integrated practice of childhood healthcare. Trends over the past two decades have revealed that fundamental cause theory may be useful in explaining the persistence of critical public health advances. Today, the impact of socio-economic conditions and knowledge networks on the decision to vaccinate may be more important than it has been in decades.

Freese and Lutfey [21] document the importance of social networks in influencing healthcare choices. These networks can generate spillover effects, positive or negative, that impact individual healthcare choices. Additionally, the different socioeconomic positions of individuals in these networks further influence the healthcare information received and choices that an individual makes. Further, individuals and families of lower socioeconomic status are argued to have greater social distance, while positive healthcare spillovers resulting from social networks are more likely in an environment of denser social embeddedness [21].

The research of Polonijo and Carpiano [22] has found that knowledge of the human papillomavirus (HPV) vaccine is significantly correlated to a mother's education, household income and race/ethnicity variables. A critical contribution of this research is the exploration of the role of vaccine knowledge and healthcare professional recommendation in reducing disparities and improving vaccine completion. While knowledge is a critical factor in one model, this impact is tempered once healthcare professional recommendation is controlled for. Their results reveal that healthcare professional recommendation has a robust independent relationship with HPC vaccine series completion and that this further reduces education disparities in uptake. Finally, their research finds no reverse disparities in patterns of education, income and race/ethnicity vaccination patterns [22]. This is an important finding as there is concern that reverse disparities may exist with regard to childhood immunization patterns today.

A number of studies highlight the importance of specific social, economic or demographic variables in understanding vaccine rates. An older study found that whether a child has healthcare coverage is an important predictor of childhood immunization [23]. For the uninsured, vaccinations can be obtained at 'free' clinics but this can involve opportunity costs that are not worth taking for low income families, such as parental time from work, long waiting lines, and long travel times. Polonijo and Carpiano [22] propose that publically funded, school-based programs may be important models to consider for reducing HPV disparities.

Several studies from the developing world prove instructive in considering the types of variables that may impact rates of immunization. In a study of a 12-county area of China, accessibility to immunization determined by the fee structure of each immunization was found to be significantly related to a higher rate of immunization [24]. A related study in India determined that many children were only partially immunized because the parents were so engaged in livelihood activities [25]. Compared to the USA, these countries have very different economic and healthcare challenges. However, these studies underscore the importance of poverty and cost of immunization, which remain relevant to all families wherever they live.

Munthali [26] found that children in urban Malawi have a much higher rate of immunization than children in rural areas. In 2000, 88 % of Malawi mothers who had received a secondary school education had children who were fully vaccinated. This is compared with the roughly 60 % of mothers with little or no education who had their children fully vaccinated [26]. Rural areas have barriers to healthcare access, in addition to possible income, information and other barriers [27]. A 2014 study found substantial regional variation in immunization rates across Madagascar [28]. This research highlights that reported average coverage rates in countries may be masking wide discrepancies in regional immunization rates [29]. With variations in geographic immunization uptake there is the potential for regions to have compromised herd immunity, compromising these populations further.

More education, higher income, more knowledge about and positive attitudes toward immunization, and health insurance are all correlated with higher rates of immunization [30]. Nath et al. [25] found that a child with an illiterate mother had an approximately four times greater chance of being partially immunized than that of a literate mother. Davis et al. [29] found that income and wealth were important variables in understanding whether families choose to receive medical care, including immunization. Berkley et al. [31] confirm that wealthier educated families

living in urban areas are more likely to have fully immunized children. Clouston et al. [28] verify the strong significance of both household wealth and parent's education in improved childhood vaccination rates. The age of the mother and higher birth order are both highly correlated with full immunization status. Additionally, if more children are born to a family, there is less likelihood of the later born children receiving their complete childhood immunization [32]. The benefits of immunizing another child are reduced as more children in the family are immunized. Munthali [26] documents that children born into large families often have a low vaccination uptake.

Some studies also find that race is an important predictor of immunization. Research documents that some racial groups have a higher percentage of fully vaccinated children than others [33]. On average, African-Americans in O'Malley's [33] Medicare immunization study had less formal education, lower incomes, and poorer health status. Even when controlling for education, income, and insurance coverage, the immunization rates of African-Americans was never as high as whites. Overall, this background literature confirms that socioeconomic status and other demographic characteristics can be important predictors of childhood vaccine uptake. Current vaccination trends in the USA underscore the importance of revisiting this research and reviewing current and potential policy approaches.

3 Methods

This research uses data from the Center for Disease Control and Prevention's (CDC), National Immunization Survey. Since 1994, the National Immunization Survey (NIS) has been conducted by a subdivision of the CDC as part of the Childhood Immunization Initiative (CII). These initiatives were established in order to reduce the cost of vaccines, improve vaccine usage, improve delivery of vaccines to children, and enhance awareness of vaccination and its benefits [2]. The geographic composition of the CDC survey changes each year so matching geographies from one year to the next is not possible. As such, this research analyzes 1 year, 2007, for demographic and socioeconomic predictors of childhood immunization. Study limitations precluded researchers from analyzing additional years of data but future research should consider incorporating additional years of data with geographic and other covariates included.

The NIS uses a random digit dialing (RDD) telephone survey to identify households containing children in the target age range and interviews the adult who is most knowledgeable about the child's vaccinations. With consent of the child's parent or guardian, the NIS also contacts (by mail) the child's healthcare provider(s) to request information on vaccinations from the child's medical records. Samples of telephone numbers are drawn independently, for each calendar quarter, within selected geographical areas, or strata.

In 2007, there were 64 geographic strata for which vaccine coverage levels can be estimated, including 14 primarily urban city/county areas (including the District of Columbia). The remaining 50 are either an entire state or a "rest of state" area. This design makes it possible to produce annual estimates of vaccination coverage levels within each of the 64 estimation areas with a specified degree of precision (a coefficient of variation of approximately 7.5 %). Further, by using the same data collection methodology and survey instruments in all estimation areas, the NIS produces comparable vaccination coverage levels among estimation areas and over time.

For the 2007 NIS, the household interviews began on January 4, 2007 and ended on February 14, 2008. Provider data collection extended from February 2007 to April 2008. A total sample of approximately 4.5 million telephone numbers yielded household interviews for 24,807 children, 17,017 of whom had provider data adequate to determine whether the child was up-to-date with respect to the recommended immunization schedule. The 2007 NIS public-use data file contains data for the 24,807 children with completed household interviews, and more extensive data for the 17,017 children with adequate provider data (including 128 zero-shot children). Of the 17,017 children, 2066 did not have complete immunization records. Logistic regression was used for this model. As logistic regression precludes missing dependent variables, these observations were excluded from the model. Our final sample is 14,951 children.

The design and implementation of the NIS sample involved four procedures. First, statistical models predict the number of sample telephone numbers needed in each estimation area to meet the target precision requirements. Second, the sample for an estimation area is divided into random sub-samples called replicates. By releasing replicates as needed, it is possible to spread the interviews for each sampling area evenly across the entire calendar quarter. Third, an automated procedure eliminates a portion of the non-working and non-residential telephone numbers from the sample before interviewers dial them. Fourth, the sample telephone numbers are matched against a national database of residential telephone numbers in order to obtain usable mailing addresses for as many sample households as possible. To promote participation in the NIS, an advanced letter is sent to these addresses approximately two weeks prior to the household interview.

Our dependent variable will describe whether a sample of preschool-age children is fully vaccinated, as verified by their vaccination provider. Given this, we will include a

dummy variable for first-born children to determine their probability of full vaccination.

The independent variables in this research are motivated by the diverse literature on immunization practice. Whether a child had healthcare coverage has been documented as a potential contributor to whether a child is immunized in the USA. Thus, health insurance was included in the model.

Given that cost can be a barrier to immunization, poverty status is also included in the model. While the definition of poverty can vary widely in the literature, we utilize the US Department of Health and Human Services poverty guidelines based on family size. Income and wealth are important predictors of immunization and are also included as independent variables. Income was included in the model, based on family size (above poverty, at poverty, and below poverty). To account for the importance of geography, a variable was included to indicate census region (Northeastern, Midwest, Southern, and Western).

Age and education level of the mother have been confirmed as additional determinants of immunization. The variable for mother's age was classified into three groups. In the model, mother's education level was categorized as <12 years of schooling, 12 years of schooling, >12 years of schooling but not a college graduate, and college graduate.

The variable for race was broken into four categories, Hispanic, non-Hispanic black only, non-Hispanic white only, and non-Hispanic other plus multiple race. Finally, while gender is not likely to be a determinant of immunization in the USA, this model also controls for gender of the child.

Of this sample, 27.4 % of observations were individuals living below poverty, 51 % were white, 12.5 % were black, and 27.5 % were Hispanic. Nearly one-quarter of the participants were from the West, 37.6 % from the South, 22.6 % from the Midwest, and 15.7 % from the Northeast. Regarding mother's education, 11.8 % of our sample had <12 years of schooling, 18.6 % had 12 years of schooling, 28.1 % had >12 years but had not finished university, and 41.5 % had a university degree.

A measure that the NIS does not include in their data set is social networking among parents or how parents receive information on vaccination. For example, if mothers decide not to vaccinate their children because they hear from their friends (who have also chosen not to vaccinate their children) that doing so causes autism, then there is a cluster of vulnerable children. Being able to understand and document why families make this choice and where they receive immunization information from could be valuable in a model like ours. These data limitations will likely be more important for future research efforts.

Our research utilizes a binary outcome model to characterize predictors of childhood immunization. These are models in which the dependent variable indicates one of two mutually exclusive groups in which the outcome or choice must fall. The probability of one outcome is p; while the probability of the alternative outcome is $(1-p)$. In this model, the child will be either fully vaccinated, or not [34]. Further explanation of the binary outcome model can be found in the electronic supplementary material.

Using SAS statistical software, a logistic regression model was estimated to predict whether a preschool-age child in the USA in 2007 was fully vaccinated based on the range of demographic and socioeconomic variables previously described. The model characterizes the variable fully vaccinated child as one.

4 Results

The Hosmer and Lemeshow test performs the goodness-of-fit test for the binary response logistic model. A large P value (>0.05) usually suggests that the fitted model is an adequate model. In this study the test's P value of (0.1409) indicates that the model is an adequate prediction. The overall logistic regression model was highly significant at the 5 % level as indicated by the Likelihood ratio, Wald and Score tests of the global null hypothesis that the model parameters are significant. Table 1 provides the odds ratio estimates. As an example, results reveal that the odds ratio of a child born with health insurance being immunized, compared to a child born without health insurance, is 1.077 [95 % confidence interval (CI) 0.999–1.161] given this set of demographic and socioeconomic characteristics. While the health insurance variable was not significant, significant variables in the model include categories of educational attainment, first born child, race and ethnicity, age of mother, and census region. If the 95 % CI does not include the value of one, the association is significant.

5 Discussion

This model does not definitively reveal that later born children are less likely to get fully vaccinated than first born children. The odds of a first born preschool-age child being fully vaccinated, compared to a second born or later born child, is 0.819 (95 % CI 0.76–0.88). This does not confirm Steele's [32] work that the more children in a family, the less likely later born children will receive their full set of childhood immunizations. While additional research is needed to confirm these results over time, these results are positive in that families may be equally as likely to vaccinate all children in a family as the first born.

Table 1 Odds ratios for logistic regression

Odds ratio estimates	Point estimate	95 % confidence limits	
Less than 12 years of schooling versus college graduate	0.725	0.627	0.837
12 years of schooling versus college graduate	0.768	0.686	0.86
Greater than 12 years of schooling versus college graduate	0.808	0.738	0.885
First born child versus second born or later	0.819	0.763	0.88
Hispanic versus Non-Hispanic multiple race	1.162	1.009	1.338
Non-Hispanic Black versus Non-Hispanic multiple race	1.132	1.003	1.278
Non-Hispanic White versus Non-Hispanic multiple race	0.922	0.778	1.094
Mother's age less than 19 years old versus mother's age ≥30	0.819	0.626	1.071
Mother's age between 20 to 29 years old versus mother's age ≥30	0.866	0.798	0.941
Income greater than $75k versus non-reported income	1.093	0.898	1.33
Income above poverty but below $75k versus non-reported income	0.936	0.775	1.13
Income below poverty level versus non-reported income	0.888	0.728	1.084
Northeast Region of U.S. versus the Western region of U.S.	1.404	1.249	1.578
Midwest Region of U.S. versus the Western region of U.S.	1.162	1.048	1.287
Southern Region of U.S. versus the Western region of U.S.	1.27	1.163	1.387
If child had insurance versus if child did not have insurance	1.077	0.999	1.161

Steele's work is almost twenty years old and a variety of intervening socioeconomic, demographic, and other factors may have changed the nature of the relationship found in this work.

The geography variable is often significant in health outcomes research and this is confirmed in this analysis. The odds ratios of a child being immunized born in the Northeast, compared to a child born in the West, is 1.40 (95 % CI 1.249–1.578). This confirms that a child born in the Northeastern USA is more likely to be immunized than a child born in the Western USA. As previously mentioned, the Western region is the area of the USA where there have been clusters of nonmedical vaccine exemptions. This region has seen influential anti-vaccine propaganda, with some state exemption rates reaching over 5 % [16]. Comparatively, a child born in the South, versus a child born in the West, is 1.27 (95 % CI 1.163–1.387) times more likely to be immunized.

All levels of education were found to be significant, with those mothers having >12 years of schooling slightly more likely to vaccinate their children. Mothers with a university degree and those with less than a university degree but more than a high school education were slightly more likely to immunize their children than mothers with a high school education or less. This reaffirms previous research that children whose mothers are more educated have increased immunization uptake [26]. Finally, all race categories were found to be significant except for non-Hispanic white versus Non-Hispanic other.

Overall, the model developed in this paper seems to hold well across the logistic distribution, indicating that our independent variables are significant in predicting whether or not a preschool-age child will be vaccinated. Overall, these models reveal that demographic and socioeconomic characteristics are predictors of childhood immunization and if leveraged appropriately can assist policymakers and public health officials to understand immunization rates and craft policy to improve them.

5.1 Policy Approaches to Immunization

There are numerous policy options and theoretical approaches for how to improve US vaccination uptake. Research reveals that an outcome-based approach to immunization policy will not improve vaccination coverage and may compromise it further. Even when healthcare providers have the data, skill sets, and materials to produce immunization outcomes, there may still be an under-utilization of this service [3]. A study in India found that agents who were providing vaccines were so focused on accomplishing numerical targets of vaccine uptake that they did not take the time to explain to the patients the purposes or benefits of the vaccines [35]. This caused uncertainty and fear about vaccinations in the villages and did not necessarily accomplish the results of increased vaccine uptake.

One option to induce demand and supply of vaccinations is an individual mandate combined with incentives and opportunities for healthcare providers. Sweden was one of the first countries to mandate vaccinations in 1816. Five years later, nearly 80 % of all newborn babies were being vaccinated against small pox (the only childhood vaccination available at the time). Numerous institutional factors played a role in achieving this result. There was favorable

press for vaccination coverage; nearly 75 % of articles published during that time period advocated the benefits of vaccination. In addition, the ability to vaccinate was granted to other medical officers, a role that had previously only been legally performed by physicians [36].

Allowing numerous types of medical officers to provide vaccinations has become commonplace in the USA as nurses, pharmacists, physician's assistants, and many other healthcare professionals can now perform vaccinations. However, there remain many unvaccinated families and individuals in the USA. If the current trend continues, many parts of the country will experience regular disease outbreaks resulting in sickness and death [37]. This research begins to explore which demographic and socioeconomic characteristic of US children are most likely to be associated with vaccination coverage. Knowing these characteristics allows policymakers to target programs to specific population groups with the ultimate goal of increasing overall vaccination rates. The next section reviews the methodology for the prediction model.

Nearly 2.1 million US children are not fully vaccinated. Even the children who are vaccinated are often not vaccinated on time [38]. The USA has an immunization approach that has worked relatively well for over 50 years. While many of these approaches still work successfully, the current trend in some regions points to a critical need to review and potentially revisit immunization policy across the USA. The potential for these regional "hot spots" of non-immunizing families to compromise broader public health is too important for us not to consider more fully. As one example, the diverse, and often confusing, state immunization exemption policies underscore the need for new thinking on immunization public policy. With this in mind, are there specific categories of children that could be targeted with new public policy efforts? Furthermore, are there new or innovative approaches to immunization efforts that could turn the tide of this trend? These are all important questions for research.

Global research on immunization finds that "the contribution of wealth-related inequality to the child and maternal health service coverage gap differs by country and type of health service, warranting case-specific interventions [28, 39]". The Global Vaccine Action Plan (GVAP) frames immunizations as a basic human right; one that should emphasize and support equitable vaccine uptake in such a way that public health remains the number one objective. The GVAP further underscores the ongoing concern of geographic inequities in vaccine rates across countries, whether these are driven by income, rurality, education or some combination of factors [31]. Demand and supply side barriers are both relevant considerations in vaccine public policy. However, gaps in geographic vaccine rates may reveal supply-side barriers [40]. Given the importance of geographic considerations, future research should consider including geographic characteristics of immunization rates to better understand reasons for immunization patterns across the USA. Anecdotal evidence of declining rates of immunization across the USA points to the importance of information and social networking on vaccine uptake. Polonijo and Carpiano [22] confirm that both of these elements are important for full HPV vaccination but add that physician information may supersede other social impacts. Understanding the social networking environment of childhood immunization in the USA is an important future research question and one that may also yield interesting regional variations. Understanding the role of the physician or medical provider in these environments is an additional question for future research. We believe that targeted policy efforts, like public information campaigns, public school provision and information, in targeted communities could be critical to reversing the trends of falling rates of full childhood immunization.

6 Conclusion

Overall, this research confirms that the likelihood of childhood immunization is significantly impacted by socioeconomic and demographic characteristics. This, and other similar research, validates the idea of targeted policy efforts that could improve immunization rates among specific groups or in specific regions. Innovative efforts in other nations may be instructive in our efforts to refocus childhood immunization practice. However, focusing efforts on regional differences, low-income, and less educated families are all important considerations in the development of future policy efforts. Earlier policy research reveals that changing this trend will likely require a multi-pronged policy approach; one that incentivizes families to have their children vaccinated, supports medical professionals who provide vaccinations and encourages and supports state efforts to restrict the wide range of nonmedical immunization exemptions [41, 42]. Immunization is a public health issue that demands our public attention and this research adds to our understanding of both the family characteristics associated with and the predictors of childhood immunization.

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contributions to analyzing and interpreting results and revising and editing the manuscript for intellectual content. While the first author is the guarantor of the overall content, both authors have approved the final version of the manuscript.

References

1. Doucleff M. How vaccine fears fueled the resurgence of preventable diseases. National Public Radio. 2014. Available at: http://www.npr.org/blogs/health/2014/01/25/265750719/how-vaccine-fears-fueled-the-resurgence-of-preventable-diseases.
2. Centers for Disease Control and Prevention. Vaccination coverage rates and prevention. 2011. Available at: http://www.cdc.gov/nutrition/.
3. Elam-Evans LD, Kolasa M, Singleton JA, Yankey D. National, state, and selected local area vaccination coverage among childrenaged 19–35 months-United States, 2013. Morb Mortal Wkly Rep. 2014;63(34):741–8.
4. The Centers for Disease Control and Prevention. Measles. 2011. Availiable at: http://www.cdc.gov/measles/.
5. Johnson M, Bradley K, Mendus S, Burnsed L, Clinton R, Tiwari T. Vaccine preventable disease among homeschooled children: two cases of tetanus in Oklahoma. Pediatrics. 2013;132(6):1686–9.
6. California Department of Public Health. Pertussis Report. 2013. Available at http://www.cdph.ca.gov/programs/immunize/Documents/PertussisReport2012-04-24.pdf.
7. Lee EO, Rosenthal, L, Scheffler G. The effect of childhood vaccine exemptions on disease outbreaks. Center for American Progress. 2013. Available at: http://www.americanprogress.org/issues/healthcare/report/2013/11/14/76471/the-effect-of-childhood-vaccine-exemptions-on-disease-outbreaks/.
8. Jaslow R. CDC: vaccination rates among Kindergartners high, but exemptions worrisome. CBS News. 2013. Available at: http://www.cbsnews.com/news/cdc-vaccination-rates-among-kindergartners-high-but-exemptions-worrisome/.
9. Omer S, Pan W, Halsey N, Stockley S, Moulton L, Navar A, Pierce M, Salmon D. Nonmedical exemptions to school immunization requirements. J Am Med Assoc. 2006;296(14):1757–63.
10. Omer SB, Salmons DA, Orenstein WA, deHart MP, Halsey N. Vaccine refusal, mandatory immunization, and the risks of vaccine-preventable diseases. N Engl J Med. 2009;360:1981–8.
11. Robinson SG, Timmons A, Duncan L, Gaudino JA, Priedeman M, Collins H. What Ashland parents told us about religious exemptions. State of Oregon, Department of Human Services, Immunization Program. 2003. Available at: http://www.dhs.state.or.us/publichealth/imm/law/ashlandfinalreport.pdf.
12. Hodge JG, Gostin LO. School vaccination requirements: historical, social, and legal perspectives. Ky Law J. 2002;90:831–91.
13. Johns Hopkins Bloomberg School of Public Health. Vaccine Exemptions. 2014. Available at: http://www.vaccinesafety.edu/cc-exem.htm. Accessed May 2014.
14. Rota JS, Salmon DA, Rodewald LE, Chen RT, Hibbs BF, Gangarosa EJ. Processes for obtaining nonmedical exemptions to state immunization laws. Am J Public Health. 2001;91:645–8.
15. Salmon DA, Sapsin JW, Teret S, Jacobs RF, Thompson JW, Ryan K, Halsey NA. Exemptions to school immunization requirements: the role of school level requirements, policies, and procedures. Am J Public Health. 2005;95(5):778–83.
16. Blank NR, Caplan AL, Constable C. Exempting schoolchildren from immunizations: states with few barriers had highest rates of nonmedical exemptions. Health Aff. 2013;32(7):1282–90.
17. Zhou F, Santoli J, Messonnier ML, Yusuf HR, Shefer A, Chu SY, Harpaz R. Economic evaluation of the 7-vaccine routine childhood immunization schedule in the United States, 2001. Arch Pediatr Adolesc Med. 2005;159(12):1136.
18. Gauri V, Khaleghian P. Immunization in developing countries: Its political and organizational determinants. World Dev. 2002;30(12):2109–32.
19. Phelan JC, Link BG, Tehranifar P. Social conditions as fundamental conditions of health inequalities: theory, evidence, and policy implications. J Health Soc Behav. 2010;51:S28–40.
20. Adler NE, Stewart J. Health disparities across the lifespan: meaning, methods, and mechanisms. Ann N Y Acad Sci. 2010;1186:5–23.
21. Freese J, Lutfey K. Fundamental causality: challenges of an animating concept for medical sociology. In: Pescosolido BA, Martin JK, McLeod JD, Rogers A, editors. Handbook of the sociology of health, illness, and healing: a blueprint for the 21st century. New York: Springer; 2011. p. 67–81.
22. Polonijo AN, Carpiano RM. Social inequalities in adolescent human papillomavirus (HPV) vaccination: a test of fundamental cause theory. Soc Sci Med. 2013;82:115–25.
23. Hemenway D. Teaching tools: economics of childhood immunization. Econ Inq. 1994;32:519–26.
24. Xie J, Dow WH. Longitudinal study of child immunization determinants in china. Soc Sci Med. 2005;61(3):601–11.
25. Nath B, Singh J, Awasthi S, Bhushan V, Kumar V, Singh S. A study on determinants of immunization coverage among 12–23 months old children in urban slums of Lucknow district, India. Indian J Med Sci. 2007;61(11):598.
26. Munthali AC. Determinants of vaccination coverage in Malawi: evidence from the demographic and health surveys. Malawi Med J. 2007;19(2):79–82.
27. Lydon P, Beyai PL, Chaudhri I, Cakmak N, Satoulou A, Dumolard L. Government financing for health and specific national budget lines: the case of vaccines and immunization. Vaccine. 2008;26(51):6727–34.
28. Clouston S, Kidman R, Palermo T. Social inequalities in vaccination uptake among children aged 0–59 months living in Madagascar: an analysis of Demographic and Health Survey data from 2008 to 2009. Vaccine. 2014;32(28):3533–9.
29. Davis M, Zimmerman J, Wheeler J, Freed G. Childhood vaccine purchase costs in the public sector: past trends, future expectations. Am J Public Health. 2002;92(12):1982–7.
30. Hinman AR. Financing vaccines in the 21st century: recommendations from the National Vaccine Advisory Committee. Am J Prev Med. 2005;29(1):71–5.
31. Berkley S, Chan M, Elias C, Fauci A, Lake A, Phumaphi J. Decade of vaccines. Foreword. Vaccine. 2013;31:B1–B2.
32. Steele F, Diamond I, Amin S. Immunization uptake in rural Bangladesh: a multilevel analysis. J Roy Stat Soc Ser A (Statistics in Society). 1996;159(2):289–99.
33. O'Malley AS, Forrest CB. Immunization disparities in older Americans determinants and future research needs. Am J Prev Med. 2006;31(2):150–8.
34. Cameron AC, Trivedi PK. Microeconometrics: methods and applications. Cambridge: Cambridge Univ Press; 2005.
35. Streefland P, Chowdhury AMR, Ramos-Jimenez P. Patterns of vaccination acceptance. Soc Sci Med. 1999;49(12):1705–16.
36. Sköld P. From inoculation to vaccination: smallpox in Sweden in the eighteenth and nineteenth centuries. Popul Stud. 1996;50(2):247–62.
37. The Centers for Disease Control and Prevention. Figure depicting coverage with individual vaccines from the inception of NIS, 1994 through 2012. 2013. Available at: http://www.cdc.gov/vaccines/imz-managers/coverage/nis/child/figures/2012-map.html.
38. Luman ET, Barker LE, McCauley MM, Drews-Botsch C. Timeliness of childhood immunizations: a state-specific analysis. Am J Public Health. 2005;95(8):1367–73.

39. Hooseinpoor AR, Victora CG, Bergen N, Barros AJ, Boerma T. Towards universal health coverage: the role of within—country wealth-related inequality in 28 countries in sub-Saharan Africa. Bull World Health Organ. 2011;89:881–9.
40. Ndirangu J, Barnighausen T, Tanser F, Tint K, Newell ML. Levels of childhood vaccination coverage and the impact of maternal HIV status on child vaccination status in rural Kwazulu-Natal, South Africa. Trop Med Int Health. 2009;14: 1383–93.
41. Eichler R. Can "pay-for-performance" increase utilization by the poor and improve the quality of health services? Discussion paper for the first meeting of the working group on performance-based incentives. Washington, DC: Centre for Global Development. 2006. Accessed at:http://www.cgdev.org/section/initiatives/_active/ghprn/workinggroups/performance.
42. Forbes M, Lynn LE. How does public management affect government performance findings from international research? J Public Adm Res Theory. 2005;15(4):559.