

Geo-spatial Patterns in Human Papillomavirus Vaccination Uptake: Evidence from Uninsured and Publicly-Insured Children in North Carolina

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Abstract (239 words)

Background: Human papillomavirus (HPV) vaccination coverage is far below the national objective set by Healthy People 2020. This paper explores spatial patterns in HPV vaccination uptake.

Methods: Secondary data for publicly-funded HPV vaccinations among age-eligible children from 2008 through 2013 from the North Carolina Immunization Registry (NCIR) were used in 2014 in an ecological analysis at the ZIP code tabulation area (ZCTA) level. We tested for spatial autocorrelation in unadjusted HPV vaccination rates using choropleth maps and Moran's I. We estimated non-spatial and spatial negative binomial models with spatially correlated random effects adjusted for demographic, economic, and healthcare variables drawn from the 2010 U.S. Census Bureau, 2008-2012 American Community Survey, 2010 ZIP Business Patterns, and the 2012-2013 Area Resource File.

Results: The NCIR revealed areas of especially low rates in publicly-funded HPV vaccinations among uninsured and means-tested, publicly insured children. For boys, but not girls, ZCTAs tended to have HPV vaccination rates that were similar to their neighbors. This result was partially explained by included ZCTA characteristics, but not wholly.

Conclusions: To the extent that the geo-spatial clustering of vaccination rates is due to causal influences from one ZCTA to another (e.g., through information networks), targeting interventions to increase HPV vaccination in one area could also lead to increases in neighboring areas.

Impact: Spatial targeting of HPV vaccination, especially in clusters of low vaccination areas, could be an effective strategy to reduce the spread of HPV and related cancers.

Key words: human papillomavirus; vaccination; spatial analysis

Introduction

Human papillomavirus (HPV) is the most common sexually-transmitted infection in the United States, causes genital warts, and is associated with cervical, vaginal, vulvar, anal, penile, and throat cancers (1). In June 2006, the US Food and Drug Administration (USDA) approved the use of a quadrivalent HPV vaccine to protect against four types of HPV. In 2007 the US Advisory Committee on Immunization Practices (ACIP) began recommending the three-dose vaccine regimen for all girls aged 11 to 12 years, but the vaccine may be administered as early as age 9, with catch-up vaccination for girls and women ages 13 to 26 (2). In 2010 the ACIP permitted the use of HPV vaccination for males aged 9 through 26, with full recommendation for use in males in the same manner as females in 2011 (3). The vaccination has been shown to be effective, and potentially cost-effective, in protecting against the targeted strains of HPV and related cancers (4-8).

However, HPV vaccination coverage is far below the national objective set for girls (80%) by Healthy People 2020 (no goal was set for boys) (9). In 2012, completion of the three dose series at ages 13 to 17 was only 33% for girls and 7% for boys (1, 9). In North Carolina, HPV vaccine initiation (i.e., at least one dose) increased modestly over time for girls ages 11 to 17 years: 2008 = 34%, 2009 = 41%, and 2010 = 44% (10), but remains below the national goal.

Vaccination is of particular importance for under- and uninsured children, who are less likely to be vaccinated(11, 12) and therefore more likely to become infected(13). Several barriers to HPV vaccination exist, including low levels of provider recommendation(14), parental concerns about the vaccine's effect on sexual behavior and perceptions of risk(14), religious affiliation(14), and low access to the health care system (15). Area-level variables associated with lower HPV vaccination rates include poverty (12, 16), rural areas (15), pediatric specialty clinics (17), and distance to the place of vaccination (18).

Previous studies have focused on spatial patterns of HPV-associated cancers (19) and cervical cancer screening, incidence, and mortality (20, 21). For example, Appalachia, which includes western North Carolina, is an area with a high burden of cervical cancer and lower HPV vaccination rates (22). These studies suggest that spatial targeting of HPV vaccination could be an effective strategy to reduce the spread of HPV and related cancers, especially in areas of low cervical cancer screening (19-22).

This study explores geo-spatial patterns in HPV vaccination uptake over time among age-eligible, uninsured and means-tested, publicly-insured children in North Carolina. To our knowledge, this study is one of the first to investigate geo-spatial patterns in HPV *vaccination*(18). Using vaccination registry data, we conducted an ecological analysis of publicly-funded HPV vaccination rates to 1) characterize trends in uptake between 2008 and 2013 and 2) determine if vaccination rates tend to cluster geographically. The analysis will test the extent to which HPV vaccination rates cluster geographically due to similar demographic, economic, and health characteristics. Analyzing vaccination clustering provides a more complete picture of HPV-associated cancer occurrence, screening, incidence, and mortality. The results will identify new correlates of low HPV vaccination rates in areas of need. The results can also be used to geographically target areas of low coverage for interventions to increase HPV vaccination.

Materials and Methods

Data

In 2014, we collected and analyzed data for publicly-funded HPV vaccinations among age-eligible children from 2008 through 2013 from the North Carolina Immunization Registry (NCIR). The NCIR is a secure, web-based clinical tool to provide official immunization information to the state (23). The registry's primary users are local health departments (100% participate) and private provider offices that receive vaccines from the federally funded Vaccines for Children (VFC) program (over 90% of offices that receive VFC vaccines participate). The VFC provides vaccines at no cost to children who otherwise

might not be vaccinated because of inability to pay (24). Health care providers who receive VFC vaccines are required to document administration of those vaccines in the NCIR (approximately 95%) or via an alternative hard copy form (approximately 5% that are not captured in the NCIR). To ensure complete records for patients in the registry, our analysis sample included children receiving publicly-funded HPV vaccinations between the ages of nine, the youngest age at which the HPV vaccination can be given, and 14 years in 2013. The NCIR contains complete vaccination history for this cohort of children, the oldest of which were nine in 2008.

We aggregated the cumulative number of publicly-funded HPV doses and the number of children receiving all three HPV doses (i.e., full series) using public funds by patient ZIP code. We then cross-walked to ZIP code tabulation area (ZCTA) using a crosswalk created by a Health Resources and Services Administration-funded project directed by the Robert Graham Center (25). ZCTAs are generalized area representations of ZIP code service areas developed by the U.S. Census Bureau to overcome the difficulties in precisely defining the land area covered by each ZIP code. The crosswalk lists all ZIP codes included in each ZCTA. For our analysis, ZCTAs can be used for mapping and provide sufficient variation across geographic areas while also having data available for area-level characteristics. We collected geographic boundary and demographic characteristics for North Carolina ZCTAs from the U.S. Census Bureau: 2013 TIGER shape files (26), 2010 U.S. Census, 2008-2012 (5-year) American Community Survey (ACS), and 2010 ZIP Business Patterns (ZBP).

We also collected county-level characteristics from the 2012-2013 Area Resource File (ARF). All variables at the county level, which cross ZCTA boundaries, were converted to ZCTAs using weighted averages of the county-level data. For count variables, we used Census calculations of the percentage of the total population of the 2010 county represented by the ZCTA/county overlap for the weights (e.g., a ZCTA that accounted for 10% of the county population received 10% of the county's medical providers). For dichotomous variables, all counties touched by the ZCTA must have a positive indicator for the ZCTA

to receive a positive value. For per-capita variables, we used Census calculations of the percentage of the total population of the 2010 ZCTA represented by the ZCTA/county overlap for the weights (e.g., a ZCTA with 90% of its population in county A and 10% in county B weighted per capita variables from county A at 90% and per capita variables from county B at 10%).

Variables

The dependent variables in the analysis were 1) the number of publicly-funded cumulative doses in the cohort from 2008 through 2013 and 2) the number fully vaccinated children (i.e., full series of three publicly-funded doses) between the ages of 9 and 14 in 2013, by ZCTA and sex. The explanatory variables included the following demographics: the population of age-eligible, uninsured and means-tested, publicly-insured children ages 9 to 14 (logged when used as exposure in count models, ACS); percent of the total population that is female (Census), Hispanic, black Non-Hispanic, or other or multi-race/ethnicity (white non-Hispanic omitted; Census); and the percent of the total population with less than high school diploma and with at least some college (high school diploma omitted; ACS). We expected ZCTA's with more females and white non-Hispanics to have higher HPV vaccination rates^{13,14}.

We adjusted for indicators of USDA-defined persistent poverty (ARF)^a and Health Professional Shortage Area (HPSA) defined by Health Resources and Services Administration (ARF)^b. We hypothesized that higher rates of poverty and HPSA status would be associated with lower HPV vaccination rates due to lower access to the vaccinations. We also adjusted for outpatient visits per capita (ARF) and the

^a The Economic Research Service, U.S. Department of Agriculture defined persistent poverty as having 20 percent or more of residents below poverty in each of the last four censuses: 1970, 1980, 1990 and 2000.

^b A ZCTA was designated as having a shortage of primary medical care professionals by the Health Resources and Services Administration if the following three criteria were met. 1) The area is a rational area for the delivery of primary medical services. 2) One of the following conditions prevails within the area: a) the area has a population to full-time-equivalent primary care physician ratio of at least 3,500:1 or b) the area has a population to full-time-equivalent primary care physician ratio of less than 3,500:1 but greater than 3,000:1 and has unusually high needs for primary care services or insufficient capacity of existing primary care providers. 3) Primary medical care professionals in contiguous areas are over utilized, excessively distant or inaccessible to the population of the area under consideration.

number of religious organizations (North American Industry Classification System code 8131) per 1000 population (ZBP). We used 2010 values for all explanatory variables.

Statistical Analysis

We conducted analyses separately for boys and girls and for cumulative doses as well as the number of children fully vaccinated. We tested for spatial autocorrelation in the unadjusted HPV vaccination rates using choropleth maps generated using Stata's user-written command *spmap*, which color code each ZCTA using quintiles for HPV vaccination rates, and Moran's I (27). Values of I greater than (less than) the expected value indicate positive (negative) spatial autocorrelation: nearby ZCTAs tend to exhibit similar (dissimilar) publicly-funded HPV vaccination rates among eligible children. We used two definitions of neighbors. Contiguous neighbors share a common border or a single common point. We also used a weighted average of all ZCTAs with each ZCTA's contribution weighted by the inverse of the Euclidean distance between the centroids of the ZCTA and the other ZCTAs.

We then estimated non-spatial count data models for HPV vaccinations at the ZCTA level. These models explore how much of the spatial autocorrelation in HPV vaccination rates is explained by observable ZCTA characteristics. Specification tests revealed evidence of over dispersion in the number of vaccinations per ZCTA, so we estimated negative binomial models that adjusted for the variables discussed above. We tested for spatial autocorrelation of the residuals (expressed as the difference between the actual and predicted values divided by the eligible population) using choropleth maps and Moran's I.

Lastly, we estimated negative binomial models with spatially correlated random effects (conditional autoregressive [CAR] models) (28). The vaccination rate was a function of ZCTA characteristics and two error terms: a standard negative binomial dispersion term and a spatial error term whose mean (conditional on the other ZCTAs) is equal to the average spatial error term among adjacent ZCTAs. We estimated the CAR model in a Bayesian framework using Markov chain Monte Carlo

(MCMC) implemented in WinBUGS. We ran 200,000 simulations of the MCMC and report summary statistics from the posterior distribution of the model's parameters using the last 50,000 simulations. See the Supplementary Methods and Materials for details of the model and estimation. We also report choropleth maps showing the quintiles of HPV vaccination rates attributable to the conditional autoregressive random effects.

Results

The percent of uninsured and mean-tested, publicly-insured children ages 9 to 14 vaccinated against HPV (full series) using public funds has increased over time (Figure 1). HPV vaccination rates for boys lagged behind those for girls in the three years after ACIP recommendation. In 2013, the median percent that have had a publicly-funded full series HPV vaccination was 3.4% for girls (inter-quartile range [IQR]: 1.4% to 5.0%) and 2.3% for boys (IQR: 0.6% to 3.7%).

On average for ZCTAs, 50 publicly-funded HPV doses were given between 2008 and 2013 for girls and 45.9 for boys, with standard deviations larger than the mean (Table 1). The number of children receiving publicly-funded full doses was much lower on average: 8.9 per ZCTA for girls and 6.8 per ZCTA for boys. ZCTAs had 224 eligible girls and 235 eligible boys on average, ranging from 1 to approximately 2,000. On average, ZCTAs were evenly divided between males and females, 20% black, non-Hispanic, 6.6% Hispanic, and had over 50% of the population with at least some college. Approximately 8% of ZCTA's were in counties with persistent poverty and 60% were HPSA.

Choropleth graphs show pockets of high- and low-HPV vaccination rate ZCTAs (Figure 2). Moran's I indicate significant positive clustering of HPV vaccination rates by ZCTA for boys using both definitions of neighboring ZCTAs (Table 2). This indicates that ZCTA's have vaccination rates for boys similar to their neighbors. Conversely, for girls, there was no statistically significant spatial autocorrelation for cumulative doses or full series rates.

The following variables were associated with higher levels of publicly-funded HPV vaccination among girls in the negative binomial count data models (Table 3, MLE columns): share of the population that was Hispanic, black non-Hispanic, and other race/ethnicity for cumulative doses (relative to white, non-Hispanic); outpatient visits per capita; religious organizations per 1000 population; and the number of uninsured and means-tested, publicly-insured children ages 9 to 14. Conversely, the following variables were associated with lower levels of publicly-funded HPV vaccination among girls: the share of the population that with less than high school education (relative to high school) and HPSA. Results for HPV vaccination among boys were similar in sign and statistical significance to girls except that the associations with other race/ethnicity, HPSA, and religious organizations per 1000 population were less significant. The estimates of α were statistically significantly different from zero, indicating over dispersion in the data.

Conditional on the explanatory variables, there is still significant geo-spatial clustering of HPV vaccination rate residuals for boys. Moran's I values are much lower once we adjust for the covariates, but the p-values indicate statistically significant positive clustering in the residuals (Table 2). There is no evidence of spatial autocorrelation in the residuals for girls.

Compared to the maximum likelihood estimates that do not account for spatial autocorrelation, the coefficients (point estimates for MLE and posterior means for CAR) for other race/ethnicity, less than high school, HPSA (except girls cumulative doses), and outpatient visits per capita (boys) are no longer significant in the CAR model (i.e., the posterior 95% credible interval includes zero; Tables 3 and 4). In addition, for boys the coefficients for percent of the population that is female (positive) and persistent poverty (negative) are statistically significant in the CAR model for the full HPV series. The coefficients for Hispanic, black non-Hispanic, outpatient visits per capita (girls), and religious organizations per 1000 population (girls) are very similar in the CAR models. The CAR model's estimate of α still indicates significant over dispersion in vaccination rates, supporting the negative binomial

specification over Poisson, but the estimates are much smaller than MLE; the CAR model attributes a larger portion of the over dispersion to spatial correlation in the error terms.

We calculated the incidence rate ratio from the full series CAR estimates. A one percentage point increase in the share of the population that was Hispanic was associated with a two percent increase in the publicly-funded HPV vaccination rate for girls ($IRR = 1.02 = \exp(1.887/100)$)^c and a three percent increase for boys, holding the other covariates constant. A one percentage point increase in the share of the population that was black non-Hispanic was associated with a 0.4 percent increase in the vaccination rate for girls and a one percent increase for boys. Each additional religious organization per 1000 population in the ZCTA was associated with a 12 percent increase in the vaccination rate for girls. Persistent poverty status was associated with a 30 percent lower vaccination rate among eligible boys ($IRR = 0.70$).

Figure 3 shows quintile choropleth maps of HPV vaccination rates attributable to the conditional autoregressive random effects in the CAR model. Under the assumptions of the CAR model, these values represent spatial heterogeneity conditional on population size and the covariates included in the model. Clustering of HPV vaccination rates is evident, with areas of relatively low rates concentrated in the northeast, south, and west-central portions of the state.

Discussion

Registry data from North Carolina revealed areas of especially low rates in publicly-funded HPV vaccinations among uninsured and means-tested, publicly insured children. The spatial analysis revealed spatial autocorrelation of HPV vaccination rates among boys—ZCTAs tended to have HPV vaccination rates that were similar to their neighbors. This result was partially explained by demographic, economic, and healthcare characteristics of the ZCTAs, but not wholly. HPV vaccination rates for girls were higher than for boys, but still well below Healthy People 2020 targets. We did not detect any significant

^c Coefficient was scaled to express the variable as a percentage instead of a fraction.

geographic clustering of publicly-funded HPV vaccinations among eligible girls. Our finding of significant clustering for boys and not girls could be because the diffusion process is less advanced for boys, who display areas with early adopters.

The results of this study could be useful in helping to target areas to increase HPV vaccinations and reduce the spread of HPV within the state. Previous studies of HPV and cervical cancer burden have suggested geo-spatial targeting as an effective strategy (19-22). To the extent that the geo-spatial clustering of vaccination rates is due to causal influences from one ZCTA to another (e.g., through information networks), targeting interventions to increase HPV vaccination among eligible children in one area could also lead to increases in neighboring areas.

Several federal and state policies have attempted to increase access to HPV vaccinations by reducing out-of-pocket costs of the vaccine, including the VFC program and the inclusion of the vaccine in preventive services mandated by the Affordable Care Act. However, our results indicate that even among children qualifying for publicly-funded vaccination, rates were lower in areas of persistent poverty and shortages of providers. Therefore, access to the vaccine entails more than just lower out-of-pocket costs, including access to providers.

This study has limitations that are important for the interpretation and application of the results. Our analysis did not include privately-funded vaccines, vaccinations given by pharmacies during this period, or doses given to children who might have moved from out of state. We also focused on younger ages than earlier studies (10). Thus, the vaccination rates reported in Figure 1 are lower than in other data sources. For example, based on data from the 2012 NIS-Teen survey, the rate of full vaccination (i.e., three or more doses) by the age of 13 was 6.8% nationally and 6.6% for North Carolina. We focused on publicly-funded vaccinations, for which reporting to the NCIR was required, to minimize the extent of under-reporting for our analysis sample. The benefit of registry data is that it avoids recall and self-reporting bias present in surveys (29, 30) .

The unexpected results for the number of religious organizations could result from unmeasured differences in denominational attitudes. ZCTAs and ZIP codes were not created as geographic markers and their use in spatial analysis may lead to representational errors (31). There are alternative Bayesian specifications for spatial effects, which could generate different clusters (32, 33).

There are likely unmeasured factors that would explain the observed geo-spatial patterns in HPV vaccination rates and the differences between boys and girls. These include parental and provider attitudes, concerns about effects on sexual behavior, low perceived risk of HPV infection, and social influences (14). We believe the results motivate further analysis of clusters to find out what is driving the higher- (lower-) than expected use of HPV vaccination. This could include investigating the potential role of network effects through information transmission about HPV vaccination (positive and negative)(34) and potential free-rider problems caused by perceived herd immunity (i.e., relying on others to vaccinate to protect your child from exposure)(35).

Table 1. Summary Statistics

	Mean	SD	Min	Max
ZCTAs Used for Girls (N=751)				
Cumulative publicly-funded doses	50.0	68.4	0.0	482.0
Publicly-funded full series	8.9	12.8	0.0	97.0
Eligible pop. ^a	223.8	265.0	0.5	2,019.6
Female	0.509	0.031	0.157	0.576
Hispanic ^b	0.066	0.059	0.000	0.466
Black, non-Hispanic	0.201	0.195	0.000	0.986
Other race/ethnicity	0.041	0.070	0.000	0.786
Less than high school ^c	0.181	0.083	0.007	0.495
At least some college	0.509	0.144	0.122	0.957
Persistent poverty	0.080	0.271	0.000	1.000
Health Professional Shortage Area	0.605	0.489	0.000	1.000
Outpatient visits per capita	1.840	1.283	0.000	7.708
Religious organizations per 1000 pop.	1.180	1.460	0.000	17.340
ZCTAs Used for Boys (N=750)				
Cumulative publicly-funded doses	45.9	64.7	0.0	542.0
Publicly-funded full series	6.8	10.5	0.0	93.0
Eligible pop. ^a	234.4	281.2	0.4	1,987.8
Female	0.509	0.029	0.157	0.597
Hispanic ^b	0.066	0.059	0.000	0.466
Black, non-Hispanic	0.196	0.189	0.000	0.865
Other race/ethnicity	0.041	0.070	0.000	0.786
Less than high school ^c	0.179	0.083	0.000	0.459
At least some college	0.511	0.143	0.122	0.957
Persistent poverty	0.075	0.263	0.000	1.000
Health Professional Shortage Area	0.596	0.491	0.000	1.000
Outpatient visits per capita	1.847	1.279	0.000	7.708
Religious organizations per 1000 pop.	1.150	1.350	0.000	17.340

a. Uninsured and means-tested, publicly-insured children ages 9 to 14

b. White, Non-Hispanic is the reference group

c. High school is the reference group

Table 2. Global Test of Spatial Autocorrelation in Publicly-Funded HPV Vaccination Rates: Moran's I^a

	Girls				Boys			
	<u>Cumulative Doses</u>		<u>Full Series</u>		<u>Cumulative Doses</u>		<u>Full Series</u>	
	Unadjusted	Negative Binomial Residuals	Unadjusted	Negative Binomial Residuals	Unadjusted	Negative Binomial Residuals	Unadjusted	Negative Binomial Residuals
Contiguity Neighbors								
I	0.018	0.009	0.011	0.010	0.068	0.030	0.065	0.037
p-value	0.198	0.314	0.283	0.300	0.001	0.031	0.001	0.011
Inverse-Distance								
I	0.003	0.002	0.000	-0.000	0.008	0.002	0.008	0.004
p-value	0.057	0.107	0.286	0.315	0.000	0.020	0.000	0.001

a. The expected value of Moran's I for 751 ZCTAs is -0.001.

Table 3. Publicly-Funded HPV Immunizations among Girls: Negative Binomial Models

	Cumulative Doses		Full Series	
	MLE	CAR	MLE	CAR
Female	0.709 [-0.849,2.267]	1.093* [-0.150,2.342]	0.030 [-1.902,1.961]	0.204 [-1.873,2.331]
Hispanic ^a	1.961** [1.339,2.583]	2.069** [1.398,2.738]	1.842** [0.960,2.724]	1.887** [0.997,2.783]
Black, non-Hispanic	0.492** [0.295,0.688]	0.612** [0.345,0.874]	0.233* [-0.016,0.482]	0.430** [0.077,0.791]
Other race/ethnicity	0.422** [0.035,0.809]	0.352 [-0.175,0.890]	0.126 [-0.373,0.625]	0.091 [-0.600,0.781]
Less than high school ^b	-0.184** [-0.343,-0.025]	-0.030 [-0.931,0.908]	-0.200** [-0.399,-0.002]	-0.157 [-1.513,1.227]
At least some college	-0.372 [-1.440,0.695]	0.141 [-0.389,0.676]	-0.241 [-1.613,1.131]	0.206 [-0.570,0.990]
Persistent poverty	-0.046 [-0.634,0.543]	0.004 [-0.183,0.198]	0.012 [-0.765,0.788]	-0.063 [-0.320,0.201]
Health Professional Shortage Area	-0.100** [-0.166,-0.035]	-0.073* [-0.155,0.008]	-0.111** [-0.204,-0.018]	-0.081 [-0.191,0.030]
Outpatient visits per capita	0.035** [0.009,0.061]	0.032* [-0.001,0.064]	0.045** [0.014,0.075]	0.046** [0.003,0.088]
Religious organizations per 1000 pop.	0.082** [0.030,0.135]	0.078** [0.042,0.114]	0.108** [0.038,0.178]	0.118** [0.052,0.179]
ln(Eligible pop) ^c	0.936** [0.891,0.981]	0.935** [0.902,0.969]	1.004** [0.952,1.057]	1.011** [0.959,1.062]
Constant	3.116** [3.071,3.160]	3.075** [3.044,3.107]	1.352** [1.288,1.416]	1.243** [1.126,1.333]
α (over dispersion)	0.126** [0.103,0.155]	0.072** [0.054,0.093]	0.130** [0.098,0.171]	0.085** [0.059,0.117]
σ_u^2 (variance of spatial error term)		0.185** [0.114,0.267]		0.184** [0.092,0.291]
Observations	751	751	751	751

MLE = maximum likelihood estimation, CAR = conditional autoregressive.

Point estimates (MLE) and posterior means (CAR) reported. 95% confidence intervals (MLE) and 95% credible intervals (CAR) in brackets.

* $p < 0.10$, ** $p < 0.05$

- a. White, Non-Hispanic is the reference group
- b. High school is the reference group
- c. Uninsured and means-tested, publicly-insured children ages 9 to 14

Table 4. Publicly-Funded HPV Immunizations among Boys: Negative Binomial Models

	Cumulative Doses		Full Series	
	MLE	CAR	MLE	CAR
Female	1.522* [-0.046,3.089]	1.231 [-0.256,2.715]	1.783 [-1.899,5.465]	2.163* [-0.302,4.777]
Hispanic ^a	2.933** [2.113,3.753]	2.856** [2.065,3.614]	2.804** [1.603,4.004]	2.721** [1.677,3.785]
Black, non-Hispanic	0.578** [0.329,0.827]	0.671** [0.367,0.979]	0.644** [0.289,0.999]	0.871** [0.461,1.284]
Other race/ethnicity	0.435* [-0.046,0.916]	0.098 [-0.580,0.759]	0.216 [-0.527,0.960]	0.070 [-0.784,0.904]
Less than high school ^b	-0.232** [-0.430,-0.034]	-0.526 [-1.481,0.487]	-0.507** [-0.778,-0.235]	-0.638 [-2.229,0.950]
At least some college	-0.425 [-1.762,0.911]	0.160 [-0.404,0.746]	-0.388 [-2.087,1.312]	0.181 [-0.724,1.086]
Persistent poverty	0.179 [-0.553,0.911]	-0.026 [-0.242,0.196]	0.063 [-0.842,0.968]	-0.360** [-0.685,-0.033]
Health Professional Shortage Area	-0.076* [-0.156,0.003]	-0.025 [-0.121,0.072]	-0.054 [-0.165,0.058]	-0.031 [-0.164,0.102]
Outpatient visits per capita	0.028* [-0.004,0.059]	0.027 [-0.010,0.066]	0.034* [-0.004,0.071]	0.043 [-0.008,0.094]
Religious organizations per 1000 pop.	0.053 [-0.017,0.123]	0.059** [0.014,0.104]	0.055 [-0.037,0.148]	0.060 [-0.020,0.136]
ln(Eligible pop) ^c	0.875** [0.819,0.930]	0.896** [0.860,0.932]	0.910** [0.842,0.978]	0.916** [0.860,0.973]
Constant	3.040** [2.988,3.093]	2.967** [2.934,3.000]	1.096** [1.015,1.177]	0.996** [0.929,1.063]
α (over dispersion)	0.196** [0.160,0.239]	0.071** [0.051,0.096]	0.203** [0.147,0.283]	0.094** [0.064,0.134]
σ_u^2 (variance of spatial error term)		0.389** [0.284,0.506]		0.359** [0.226,0.519]
Observations	750	750	750	750

MLE = maximum likelihood estimation, CAR = conditional autoregressive.

Point estimates (MLE) and posterior means (CAR) reported. 95% confidence intervals (MLE) and 95% credible intervals (CAR) in brackets.

* $p < 0.10$, ** $p < 0.05$

- a. White, Non-Hispanic is the reference group
- b. High school is the reference group
- c. Uninsured and means-tested, publicly-insured children ages 9 to 14

Figure 1. Box plot of the percent of uninsured and mean-tested, publicly-insured children ages 9 to 14 vaccinated against HPV (full series) using public funds over time (N=751 ZCTAs)

Figure 2. Percent of uninsured and means-tested, publicly-insured children ages 9 to 14 vaccinated against HPV using public funds (full series, unadjusted rates)

A. Girls

B. Boys

Figure 3. Publicly-funded HPV vaccination rates (full series) attributable to conditional autoregressive random effects

A. Girls

B. Boys

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