

## Supplementary Methods and Materials: Negative Binomial Conditional Autoregressive Model

HPV vaccination rates for ZCTA  $i$  ( $y_i$ ), are assumed to be distributed Poisson:

$$y_i \sim \text{Poisson}(N_i \theta_i),$$

$$\theta_i = g_i \exp(\beta_0 + \mathbf{x}'_i \boldsymbol{\beta} + u_i),$$

where  $N_i$  is the population of ZCTA  $i$ . The vaccination rate ( $\theta_i$ ) is a function of the ZCTA characteristics ( $\mathbf{x}$ ) and two error terms. The non-spatial offset term,  $g_i$ , is the standard negative binomial dispersion term, distributed gamma with mean one:

$$g_i \sim \text{Gamma}(1/\alpha, \alpha).$$

The larger  $\alpha$  is, the greater the over-dispersion. The Poisson model corresponds to  $\alpha = 0$ . The spatial error term,  $u_i$ , is distributed normally with a mean (conditional on the other ZCTAs) equal to the average error term among adjacent ZCTAs and a variance proportional to the number of adjacent ZCTAs:

$$u_i | u_{j,i \neq j} \sim N(\bar{\mu}_i, \sigma_i^2),$$

$$\bar{\mu}_i = \frac{1}{\sum_{j=1}^N w_{ij}} \sum_{j=1}^N w_{ij} u_j,$$

$$\sigma_i^2 = \frac{\sigma_u^2}{\sum_{j=1}^N w_{ij}},$$

with  $w_{ij} = 1$  if ZCTAs are adjacent and 0 otherwise (i.e., contiguity neighbors).

We used prior distributions for the model parameters suggested by Neyens, Faes (1) that were uninformative:  $\beta_0 \sim$  uniform over the real number line,  $\boldsymbol{\beta} \sim N(0, 100000)$ ,  $1/\alpha \sim \text{exp}(1)$ ,  $\tau = 1 / \sigma_i^2 \sim \text{Gamma}(0.5, 0.0005)$ . In a sensitivity analysis, we also estimated a model using alternative priors for  $\alpha$  and  $\tau$ :  $1/\alpha \sim \text{Gamma}(0.1, 1)$  (2) and  $\tau \sim U(0, 10000)$  (3). The results were unchanged from those reported in the paper.

## References

1. Neyens T, Faes C, Molenberghs G. A generalized Poisson-gamma model for spatially overdispersed data. Spatial and Spatio-temporal Epidemiology. 2012;3:185-94. doi: <http://dx.doi.org/10.1016/j.sste.2011.10.004>.

2. George EI, Makov UE, Smith AFM. Conjugate Likelihood Distributions. *Scand J Stat.* 1993;20:147-56. PubMed PMID: WOS:A1993LL60200004.
3. Gelman A. Prior distributions for variance parameters in hierarchical models(Comment on an Article by Browne and Draper). *Bayesian Anal.* 2006;1:515-33. PubMed PMID: WOS:000207447000014.