Impact of State Public Health Spending on Disease Incidence in the United States from 1980 to 2009

Reetu Verma, Samantha Clark, Jonathon Leider, and David Bishai

Objective. To understand the relationship between state-level spending by public health departments and the incidence of three vaccine preventable diseases (VPDs): mumps, pertussis, and rubella in the United States from 1980 to 2009.

Data Sources. This study uses state-level public health spending data from The Census Bureau and annual mumps, pertussis, and rubella incidence counts from the University of Pittsburgh's project Tycho.

Study Design. Ordinary least squares (OLS), fixed effects, and random effects regression models were tested, with results indicating that a fixed effects model would be most appropriate model for this analysis.

Principal Findings. Model output suggests a statistically significant, negative relationship between public health spending and mumps and rubella incidence. Lagging outcome variables indicate that public health spending actually has the greatest impact on VPD incidence in subsequent years, rather than the year in which the spending occurred. Results were robust to models with lagged spending variables, national time trends, and state time trends, as well as models with and without Medicaid and hospital spending.

Conclusion. Our analysis indicates that there is evidence of a significant, negative relationship between a state's public health spending and the incidence of two VPDs, mumps and rubella, in the United States.

Key Words. Tycho, vaccination, VFC, CHIP, vaccine preventable diseases

The systematic promotion of public health through state and local health departments is credited with many of the vast improvements in the health of U.S. citizens in the last century (MMWR 1999; Cutler and Miller 2004; Schlipkötter and Flahault 2010). However, the resources allocated to these systems, as measured by per capita spending and workforce availability, have not kept pace with the demands of a growing population (ASTHO 2014). In 2011, only 15 percent of funding for core public health-related activities originated from the federal budget, and total per capita public health spending was \$251,

or roughly 3.1 percent, of all U.S. total health spending (Beitsch et al. 2006). Additionally, the number of full-time equivalents (FTEs) employed at public health agencies decreased from approximately 107,000 in 2010 to 101,000 in 2012 (IOM 2012).

Public health departments have played a significant role in VPD control in the United States, as evidenced by the elimination of indigenous transmission chains for polio, measles, and rubella from the United States through the administration of vaccines, especially in vulnerable populations (CDC 1999). State public health departments facilitate VPD reduction through the purchase and delivery of vaccines via programs such as the children's health insurance program (CHIP) and by funding vaccine campaigns and vaccine coverage registries (Lindley et al. 2009a,b). Medicaid also plays a key role in the prevention of disease through facilitating access to vaccines and vaccine activities (Medicaid.gov 2015). In addition, the federally funded Vaccines for Children (VFC) program was implemented in 1994 to reduce vaccine cost as a barrier to access and improve childhood vaccination rates as well (Walker, Smith, and Kolasa 2014).

In addition to the purchase and administration of vaccines, public health agencies control VPDs through a variety of approaches. Two of the most effective methods agencies employ are surveillance and monitoring of public and private health providers to identify potential outbreaks. Agencies also provide educational services to inform the public of precautions and steps to take regarding the transmission of VPDs.

Despite the integral role that public health agencies play in reducing VPDs, discretionary funds for vaccine administration at the state level have not kept up with the financial cost of providing the full schedule of vaccines (Lindley et al. 2009a,b). This deprioritization and consequent underfunding of essential public health activities by individual states has led to disparities in the levels of vaccination coverage across the United States, particularly for underinsured children and adults (Mehrotra, Dudley, and Luft 2003; Hinman, Orenstein, and Rodewald 2004; Lee et al. 2007; Sensenig 2007). These

Address correspondence to Reetu Verma, M.P.H., Department of International Health, Johns Hopkins Bloomberg School of Public Health, 4601 Embassy Circle, Apt 203, Owings Mills, MD 21117; e-mail: rverma3@jhu.edu. Samantha Clark, M.H.S., is with the International Vaccine Access Center, Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD. Jonathon Leider, Ph.D., is with the Office of Public Health Practice and Training, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD. David Bishai, Ph.D., is with the Department of Population, Family, and Reproductive Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD.

disparities, combined with the resurgence of previously rare vaccine preventable diseases such as pertussis (which had the most reported cases in 57 years in 2012) make examining the link between public health spending and the incidence of VPDs especially pertinent (CDC 2015).

As one of the primary objectives of the *Healthy People 2020* national health promotion and disease prevention initiative, increasing access to vaccination services and coverage are widely recognized as fundamental aspects of improving health and economic outcomes at both the state and national level (U.S. Department of Health and Human Services 2015). Despite the impressive gains made in improving vaccine coverage among previously undervaccinated groups by the VFC program, research indicates that gaps in access may persist within the United States (Chu, Barker, and Smith 2004; Smith et al. 2009).

Failure to access vaccines is compounded by the increasing numbers of individuals who opt out of vaccination, with the added consequence of putting additional individuals at risk (such as immunocompromised and those too young to be vaccinated) as the benefits of herd immunity are diminished.

Despite the important role that public health agencies play in reducing disease burden, the literature on the impact of investments in public health is limited (Lee and Paxman 1997). This study seeks to fill gaps in our knowledge of the effectiveness of investments in public health by examining the relationship between state VPD incidence and public health spending.

MATERIAL AND METHODS

Sources of Data

Case count-data for the vaccine preventable diseases considered in this study (mumps, pertussis, rubella) were obtained from the University of Pittsburgh's Project Tycho, which digitized the entire history of weekly Nationally Notifiable Disease Surveillance System (NNDSS) reports for the United States from 1888 to 2013 (Project Tycho 2014). Spending data were obtained from the United States Census Bureau's Division of State Finance, which, with legal authorization under Title 13 Section 182, conducts an annual survey of state government finances (CDC 1999; U.S. Census Bureau 2014). The Census of Governments collects revenue, expenditure, and debt across all government functions and all levels of government. This occurs annually at the federal and state level, and a full census is conducted every 5 years at the local level. Data on Medicaid spending are available for each state from 1980 to 2006, and the analytic sample spans all 50 states and Washington D.C. over 20 years (CMS,

2015). The availability of Medicaid data beginning in 1980, large number of missing values pre-1980, and interest in examining the differential impact following the creation of the VFC program in 1994 led to the decision to start the analysis in 1980.

The outcome (dependent) variables considered in the study are the annual counts of mumps, pertussis, and rubella cases reported in each state. Mumps, pertussis, and rubella incidence were chosen as dependent variables based on a preliminary analysis of the Tycho data to determine which VPDs had the most state-level disparity in the United States. As two previously rare diseases that have recently experienced a resurgence, an analysis of mumps and pertussis was also considered to be especially timely.

Independent variables include total state expenditure, total nonhospital-related public health expenditure, total hospital-related health expenditure, state Medicaid expenditure, birth count by race, yearly mean population, year, and an interaction term of year and state for each of the states. Expenditures were analyzed on a nonhospital, hospital, and Medicaid level to address the concern that state-reported public health spending in the census will include some clinical activities related to hospitals, clinics, and care for the poor mixed in with preventive activities devoted to vaccinating and controlling infectious disease. Thus, hospital and Medicaid spending variables were included to control for potential confounding between clinical and preventive activities funded by states, with the hypothesis being that nonhospital health spending reflects funding for public health programs (Sensenig 2007). Population and birth count were also used as controls to account for the arrival of susceptible children and subsequent dilution of state spending across competing needs in an increasingly large population. To consider the impact of the inception of the CDC's VFC Program in 1994, an independent dummy variable indicating pre- versus post-1994 counts was incorporated. An additional interaction term for this dummy variable and total state health spending was also included as an independent variable.

Other key analysis variables are listed in Table 1. The table shows that the mean counts of cases per state per year numbered in the hundreds with a wide standard deviation driven by the variable population size of each state. One way to adjust for population size might have been to express incidence as a count per child or count per total population and to express spending as per capita spending. However, it is well known that one can incur a serious bias when regressing Y/P on X/P simply because $1/P$ is on both sides of a regression. To avoid ratio bias, we regress counts of cases as the dependent variable and control for population as a separate independent variable. Toward the end

Table 1: Preliminary Data Analysis

<i>Variable</i>	<i>Mean</i>	<i>SD</i>
Incidence of mumps (no. of cases per year in state)	329	1,183
Incidence of pertussis (no. of cases per year in state)	392	1,630
Incidence of rubella (no. of cases per year in state)	197	632
White birth count	58,730	68,757
Black birth count	11,449	13,629
Population (in thousands)	9,804	33,822
Total state expenditure (in USD thousands)	21,000,000	100,000,000
Medicaid spending (in USD millions)	5,569	24,428
State health direct (nonhospital) expenditure (in USD thousands)	593,011	2,700,000
Hospital direct expenditure (in USD thousands)	888,662	3,700,000

Notes. The number of states in the study exceeds the total number of states in the United States because the data used for this analysis include U.S. islands and territories and some states in the data have been divided into regions. For the final analysis, only the 50 states and Washington DC were included.

of the study period case counts fell to zero in many states; however, across the entire time span, the average number of cases is in the hundreds (Table 1). Spending data were adjusted for inflation (year 2013) and then subjected to logarithmic transformation.

Statistical Analysis

To determine the most appropriate model for our analysis, we began by running an ordinary least squares (OLS) regression model, followed by both fixed effects models and random effects models. The OLS, fixed, and random effects models were initially compared using Akaike’s information criteria (AIC) as a means of model selection. AIC values indicated that either a fixed or random effects models would provide a superior fit for our model in this instance. A Hausman test was then run to determine whether the assumption of independence between time-dependent and time-invariant variables inherent in a random effects model was appropriate for this analysis. The results of the Hausman test indicated that this assumption was not valid, leading to the choice of a fixed effects model. The use of a fixed effects model also offered the additional advantage of controlling for time-invariant factors that could potentially affect the outcome measure.

Further analysis was performed to understand the effect of CDC’s VFC program launched in 1994 by creating a dummy variable for years post-1994 along with an interaction term consisting of this dummy variable and total state health spending.

To check the robustness of our results, spending variables were lagged 1, 2, and 3 years prior to the case count for each disease. Additional analyses were also run to test the effect of various time trends on overall case counts. These tests were performed by running the models with no time trends, national time trends (adding a year term as a covariate), and state time trends (adding a term for year and a separate interaction term for year $\times$ state as covariates). Finally, the fixed effects model with state time trends was modified by excluding Medicaid spending in one instance and hospital spending in another to assess the degree to which there was confounding in the relationship of interest due to these variables.

RESULTS

The results of the fixed effect models for each of the diseases considered in the analysis are presented in Tables 2–5 and S1 and S2 (Table S1 and S2 are available in appendix). Analysis results indicate that a 1 percent increase in public health spending was associated with statistically significantly fewer cases of mumps and rubella per year.

Medicaid spending was found only to have a statistically significant, positive association with rubella. Hospital spending was found to have a negative association with cases for all three VPDs, but none of these results were statistically significant. In the case of pertussis none of the spending coefficients were statistically significant.

Real state expenditure was found to be statistically significant for mumps and rubella. The coefficient for this variable was positive for all three VPDs considered in the analysis and varied only in magnitude.

Results incorporating national trends were extremely similar, showing a statistically significant downward trend for mumps and rubella and statistically insignificant decrease for pertussis. The coefficients for state trends varied by VPD; however, none of the coefficients were found to be statistically significant. Overall, the addition of national and state time trends to the model was not associated with a significant change in the coefficients on spending variables.

Effect of CDC's VFC Program

We found a statistically significant effect of CDC's VFC program on the case counts for mumps, pertussis, and rubella. The interaction term used in model

3 of Tables 2, 3, and 4 also had statistically significant coefficients. In the case of mumps, both the slope and the intercept changed. For pertussis, the intercept changed but not the slope. The intercept changed for rubella, but the presence of a significant coefficient on “Post 1994 (vaccines for children)” in both columns 2 and 3 creates ambiguity. The size of the effect of state expenditure after the CDC’s program was in place in 1994 is best measured in column 2 of Tables 2, 3, and 4.

Results of Lagged Models

For mumps, the increasing magnitude and statistical significance ($\beta = -54.86$ when the nonhospital spending variable was lagged 3 years) of the lagged model suggests that an increase in public health spending has a progressively larger impact in later years versus the year in which the spending occurred. This lagged effect was only statistically significant for the public health

Table 2: Comparison of Fixed Effect Regression Results for Mumps Count Pre- versus Post-1994

<i>Variables</i>	<i>(1) Mumps</i>	<i>(2) Post-1994</i>	<i>(3) Post-1994 Interaction</i>
Log real nonhospital state health spending net of capital	-38.89** [.013]	-37.91** [.015]	-33.53** [.032]
Log real state expenditure (\$1,000s)	115.34** [.018]	119.01** [.015]	163.90*** [.001]
Log real hospital health spending by states	-7.54 [.393]	-9.11 [.305]	-8.99 [.310]
Log real Medicaid spending	12.05 [.414]	11.73 [.426]	9.85 [.503]
Number of white births	0.00*** [.004]	0.00*** [.005]	0.00* [.057]
Number of black births	0.00 [.295]	0.00 [.566]	0.00 [.478]
Population	-0.05*** [.000]	-0.05*** [.000]	-0.04*** [.000]
Year	-5.55*** [.004]	-4.17** [.045]	-6.29*** [.004]
Year $\times$ State	-0.01 [.675]	-0.01 [.701]	0.00 [.971]
Post-1994 (vaccines for children program)		-28.27* [.097]	134.95** [.023]
Post-1994 interaction with log total state health spending			-10.69*** [.004]
Constant	10,651.73*** [.000]	7,802.54** [.018]	10,564.22*** [.002]
Observations	1,326	1,326	1,326
R^2	0.114	0.116	0.122
Number of state	51	51	51
Rho	0.904	0.890	0.801

Notes. p -value in brackets.

*** $p < .01$, ** $p < .05$, * $p < 0.1$.

Table 3: Comparison of Fixed Effect Regression Results for Pertussis Count Pre- versus Post-1994

<i>Variables</i>	<i>(1) Pertussis</i>	<i>(2) Post-1994</i>	<i>(3) Post-1994 Interaction</i>
Log real nonhospital state health spending net of capital	4.34 [.619]	3.65 [.676]	3.17 [.718]
Log real state expenditure (\$1,000s)	7.88 [.773]	5.31 [.846]	0.38 [.990]
Log real hospital health spending by states	2.79 [.572]	3.89 [.434]	3.88 [.435]
Log real Medicaid spending	9.03 [.274]	9.26 [.262]	9.46 [.252]
Number of white births	0.00*** [.000]	0.00*** [.000]	0.00*** [.000]
Number of black births	0.00 [.166]	0.00* [.059]	0.00* [.063]
Population	-0.02*** [.000]	-0.02*** [.000]	-0.02*** [.000]
Year	-0.86 [.422]	-1.83 [.116]	-1.60 [.197]
Year × State	0.03 [.181]	0.02 [.196]	0.02 [.231]
Post-1994 (vaccines for children program)		19.83** [.037]	1.88 [.955]
Post-1994 interaction with log total State Health Spending			1.18 [.574]
Constant	165.55 [.916]	2,164.08 [.240]	1,860.45 [.333]
Observations	1,326	1,326	1,326
R^2	0.034	0.037	0.038
Number of state	51	51	51
Rho	0.989	0.989	0.987

Notes. p -value in brackets.

*** $p < .01$, ** $p < .05$, * $p < 0.1$.

spending variable and increased in size and significance for 5 years after the spending occurred.

For pertussis, the effect of nonhospital public health spending changed direction in the lagged analysis and the effect became statistically significant only in the model where spending was lagged by 5 years.

For rubella, the effect of nonhospital public health spending increased in magnitude in the 1- and 2-year lagged models but was not statistically significant after 2 years.

In all models, the effect of Medicaid spending was reduced when the public health spending variable was lagged in progressively later years.

Effect of Medicaid Spending and Hospital Spending

In Tables 2, 3, and 4 when Medicaid spending is removed from the model (Model 5), the effect of public health spending increases by a magnitude of

Table 4: Comparison of Fixed Effect Regression Results for Rubella Count Pre- versus Post-1994

<i>Variables</i>	<i>(1) Rubella</i>	<i>(2) Post-1994</i>	<i>(3) Post-1994 Interaction</i>
Log real nonhospital state health spending net of capital	−11.73** [.047]	−10.91* [.062]	−10.37* [.078]
Log real state expenditure (\$1,000s)	80.64*** [.000]	73.39*** [.000]	76.80*** [.000]
Log real hospital health spending by states	−2.11 [.504]	−0.26 [.935]	−0.27 [.931]
Log real Medicaid spending	14.54*** [.003]	16.55*** [.001]	16.45*** [.001]
Number of white births	−0.00*** [.004]	−0.00*** [.004]	−0.00*** [.003]
Number of black births	0.00 [.107]	0.00*** [.001]	0.00*** [.001]
Population	−0.04*** [.000]	−0.04*** [.000]	−0.04*** [.000]
Year	−3.50*** [.000]	−5.06*** [.000]	−5.28*** [.000]
Year × State	0.01 [.316]	0.01 [.331]	0.02 [.279]
Post-1994 (vaccines for children program)		25.85*** [.000]	41.40** [.040]
Post-1994 interaction with log total state health spending			−1.01 [.423]
Constant	5,306.80*** [.000]	8,488.19*** [.000]	8,761.67*** [.000]
Observations	1,071	1,071	1,071
R^2	0.314	0.329	0.329
Number of state	51	51	51
Rho	0.993	0.993	0.994

Notes. p -value in brackets.

*** $p < .01$, ** $p < .05$, * $p < .1$.

four to five times for each of the diseases. This relationship is not observed, however, when the hospital spending variable is removed from the models (Model 6), as public health spending does not change considerably. This indicates that Medicaid spending is a confounder or, more likely, a mediator of the relationship between public health spending and VPD case counts. A potential reason for this is that Medicaid spending is related to both public health spending and relative disease burden.

Limitations

This study is limited in its scope and applicability for a number of reasons. The use of broad categories of spending on public health and hospitals, instead of spending specific to vaccine development and vaccination programs, allows us to see the effects on an aggregate level only, so the effects are relatively modest. To address this limitation, we explored the possibility of incorporat-

Table 5: Fixed Effects Regression Results for Mumps Count per State per Year

<i>Variables</i>	<i>(1) Mumps</i>	<i>(2) Mumps 1 year Later</i>	<i>(3) Mumps 2 Years Later</i>	<i>(4) Mumps 3 years Later</i>	<i>(5) Mumps (Model without Medicaid Spending)</i>	<i>(6) Mumps (Model without Hospital Spending)</i>
Log real nonhospital state health spending net of capital	-38.89** [.013]	-44.92*** [.006]	-43.27** [.014]	-54.86*** [.002]	-235.11*** [.000]	-38.80** [.013]
Log real state expenditure (\$1,000s)	115.34** [.018]	94.59* [.059]	66.70 [.209]	75.74 [.144]	870.18*** [.000]	107.49** [.025]
Log real hospital health spending by states	-7.54 [.393]	-4.55 [.616]	-3.54 [.719]	-1.67 [.864]	-96.82*** [.000]	
Log real Medicaid spending	12.05 [.414]	11.45 [.448]	8.38 [.591]	4.36 [.773]		13.39 [.361]
Number of white births	0.00*** [.004]	0.00* [.066]	0.00 [.201]	0.00 [.830]	-0.00* [.082]	0.00*** [.004]
Number of black births	0.00 [.295]	0.00* [.064]	0.01** [.037]	0.01*** [.005]	-0.00 [.685]	0.00 [.250]
Population	-0.05*** [.000]	-0.05*** [.000]	-0.04*** [.000]	-0.04*** [.000]	-0.09*** [.000]	-0.05*** [.000]
Year	-5.55*** [.004]	-4.18** [.037]	-3.52 [.104]	-3.37 [.119]	-18.93*** [.000]	-5.42*** [.004]
Year $\times$ State	-0.01 [.675]	-0.01 [.702]	-0.00 [.907]	0.01 [.822]	-0.30*** [.000]	-0.01 [.689]
Constant	10,651.73*** [.000]	8,219.82*** [.005]	6,850.59** [.030]	5,865.41* [.061]	44,325.97*** [.000]	10,367.69*** [.000]
Observations	1,326	1,224	1,173	1,122	1,537	1,326
R^2	0.114	0.105	0.100	0.109	0.201	0.114
Number of states	51	51	51	51	51	51
Rho	0.904	0.896	0.615	0.853	0.998	0.895

Notes: p -value in brackets.*** $p < .01$, ** $p < .05$, * $p < .1$.

ing disbursement data specific to vaccine programs (such as VFC and section 317), but ultimately determined that obtaining this information for the years considered in the analysis was not possible.

Another limitation of the model is its inability to capture the economic benefits that accrue with higher levels of vaccination. These benefits include those associated with the reduction in congenital rubella cases, the sequelae for which (including neurological problems and congenital heart defects) have serious repercussions regarding lifetime productivity and treatment costs.

A third limitation of this study concerns the potential role of case ascertainment as a confounding factor, as spending could be endogenously determined by the expected disease burden itself. Additional confounding could be present in the model as a result of our spending estimates including unobservable and dynamic state factors that may codetermine spending and health, such as employment patterns and health-seeking behavior. We attempted to control for time-invariant aspects of this potential confounding as much as possible through the use of a fixed effects model. A final limitation is that state spending on public health can simultaneously improve vaccine coverage and improve the ability to find and correctly identify cases. These effects could potentially cancel each other out as increased coverage reduces the overall case number while increased funding for disease identification increases the number of cases correctly attributed to a disease. This bias drives the effect size closer to zero and makes it harder for us to determine the effect of spending on health. The aforementioned factors indicate that even if statistically significant results are not observed, as in the case of pertussis, this is not conclusive evidence that public health spending does not affect disease incidence. For the diseases where we found that spending lowers caseloads, the above biases likely resulted in a smaller observed effect than would have otherwise occurred.

DISCUSSION

The negative association between public health spending and mumps and rubella case counts between 1980 and 2009 observed in this study are consistent with the hypothesis of public health spending playing an important role in the reduction of VPDs in the United States. In numerical terms, this analysis revealed that for an average state, a 1 percent increase in public health spending was associated with an 11.5 percent decrease in incidence of mumps and 6 percent decrease in rubella incidence.

Furthermore, the results of the lagged analysis show that the benefits of public health spending may be larger than previously estimated, as they occur not only in the year of spending, but continue to accrue, and in fact increase in magnitude, in future years.

Decreases in public health funding have come despite the CDC's assertion that "the foremost state influence on health and longevity occurs through budgetary allocations explicitly designed to improve public health" and numerous studies illustrating the ability of public health departments to combat the leading causes of mortality and morbidity in the United States (CDC 1999). One such study from Mays et al. found a strong association between increases in public health spending and reductions in mortality, especially due to cardiovascular disease and in infants (Mays and Smith 2011). Additionally, the results of these analyses are consistent with recent time series models, which estimate that changes in diet, tobacco exposure, and other measures attributable to public health programs are responsible for as much as 50 percent of the gains in life expectancy in the United States (Goldman and Cook 1984; Bunker, Frazier, and Mosteller 1994; Bunker 2001; Cutler, Rosen, and Vijan 2006; Ford and Capewell 2011). Conversely, the finding that an increase in overall state expenditure and Medicaid spending was associated with an increase in incidence of all three diseases may reflect increasing morbidity triggering higher clinical spending.

The findings of the pre-post-1994 analysis examining the impact of the creation of the VFC program indicate that the program has had a beneficial impact on the goal of reducing vaccine-preventable diseases. These results are consistent with a CDC analysis concluding that the program's elimination of cost and access barriers to vaccination have successfully increased coverage and reduced disparities (Walker, Smith, and Kolasa 2014).

Interestingly, although similar results were observed for mumps and rubella in terms of the effect of public health spending, this was not the case for pertussis. Of the three diseases in this study, pertussis creates the most immediate and severe morbidity and is more likely to be reported. This may explain the presence of high counts of pertussis and also the lack of significance of public health spending on pertussis counts.

CONCLUSION

Overall, this study shows that an increase in nonhospital public health spending is associated with a decrease in the incidence of mumps and rubella and

corroborates recent studies that have shown a strong association between public health spending and rates of preventable mortality and morbidity (Goldman and Cook 1984; Bunker, Frazier, and Mosteller 1994; Bunker 2001; Cutler, Rosen, and Vijan 2006; Ford and Capewell 2011). This analysis provides important evidence for decision makers regarding the amount of funding allocated for public health departments within individual states, and has important implications regarding the role of public health departments in reducing the disease and cost burden attributable to VPDs.

ACKNOWLEDGMENTS

Joint Acknowledgment/Disclosure Statement: David Bishai received research support from the deBeaumont Foundation. Reetu Verma received research guidance and support from Dr. David Bishai and Johns Hopkins Bloomberg School of Public Health.

Disclosures: None.

Disclaimers: None.

REFERENCES

- ASTHO. 2014. *Profile of State Public Health, Volume Three*. Washington, DC: Association of State and Territorial Health Officials.
- Beitsch, L. M., R. G. Brooks, N. Menachemi, and P. M. Libbey. 2006. "Health at Center Stage: New Roles, Old Props." *Health Affairs* 25 (4): 911–22.
- Bunker, J. P. 2001. "The Role of Medical Care in Contributing to Health Improvements within Societies." *International Journal of Epidemiology* 30 (6): 1260–3.
- Bunker, J. P., H. S. Frazier, and F. Mosteller. 1994. "Improving Health: Measuring Effects of Medical Care." *Milbank Quarterly* 72: 225–58.
- CDC. 1999. "Achievements in Public Health, 1900–1999: Control of Infectious Diseases." *MMWR. Morbidity and Mortality Weekly Report* 48 (29): 621–9.
- CDC. 2015. "Pertussis Outbreak Trends" [accessed on June 8, 2015]. Available at <http://www.cdc.gov/pertussis/outbreaks/trends.html>
- Chu, S. Y., L. E. Barker, and P. J. Smith. 2004. "Racial/Ethnic Disparities in Pre-school Immunizations: U.S., 1996–2001." *American Journal of Public Health* 94: 973–7.
- CMS. 2015. "Medicaid Statistical Information System Tables" [accessed on June 8, 2015]. Available at <http://www.cms.gov/Research-Statistics-Data-and-Systems/Computer-Data-and-Systems/MedicaidDataSourcesGenInfo/MSIS-Tables.html>

- Cutler, D., and G. Miller. 2005. *The Role of Public Health Improvements in Health Advances: The 20th Century United States*. *Demography* 42(1): 1–22. doi:10.1353/dem.2005.0002.
- Cutler, D. M., A. B. Rosen, and S. Vijan. 2006. “The Value of Medical Spending in the United States, 1960–2000.” *New England Journal of Medicine* 355 (9): 920–7.
- Ford, E. S., and S. Capewell. 2011. “Proportion of the Decline in Cardiovascular Mortality Disease Due to Prevention versus Treatment: Public Health versus Clinical Care.” *Annual Review of Public Health* 32: 5–22.
- Goldman, L., and E. F. Cook. 1984. “The Decline in Ischemic Heart Disease Mortality Rates: An Analysis of the Comparative Effects of Medical Interventions and Changes in Lifestyle.” *Annals of Internal Medicine* 101: 825–36.
- Hinman, A. R., W. A. Orenstein, and L. Rodewald. 2004. “Financing Immunizations in the United States.” *Clinical Infectious Diseases* 38 (10): 1440–6. doi:10.1086/420748.
- IOM (Institute of Medicine). 2012. *For the Public’s Health: Investing in a Healthier Future*. Washington, DC: The National Academies Press.
- Lee, P., and D. Paxman. 1997. “Reinventing Public Health.” *Annual Review Public Health* 18: 1–35.
- Lee, G. M., J. M. Santoli, C. Hannan, M. L. Messonnier, J. E. Sabin, D. Rusinak, C. Gay, S. M. Lett, and T. A. Lieu. 2007. “Gaps in Vaccine Financing for Underinsured Children in the United States.” *Journal of the American Medical Association* 298 (6): 638–43.
- Lindley, M. C., A. K. Shen, W. A. Orenstein, L. E. Rodewald, and G. S. Birkhead. 2009a. “Financing the Delivery of Vaccines to Children and Adolescents: Challenges to the Current System.” *Pediatrics* 124: S548. doi:10.1542/peds.2009-1542O.
- . 2009b. “Financing the Delivery of Vaccines to Children and Adolescents: Challenges to the Current System.” *Pediatrics* 124 (Suppl. 5): S548–57.
- Mays, G. P., and S. A. Smith. 2011. “Evidence Links Increases in Public Health Spending to Declines in Preventable Deaths.” *Health Affairs* 30 (8): 1585–93.
- Medicaid.gov. 2015. “Quality of Care Vaccines” [accessed on August 31, 2015]. Available at <http://www.medicaid.gov/medicaid-chip-program-information/by-topics/quality-of-care/quality-of-care-%E2%80%93vaccines.html>
- Mehrotra, A., R. A. Dudley, and H. S. Luft. 2003. “What’s Behind the Health Expenditure Trends?” *Annual Review Public Health* 24: 385–412.
- MMWR. 1999. “Achievements in Public Health, 1900–1999: Control of Infectious Diseases.” *Morbidity and Mortality Weekly Report* 48 (29): 621–9.
- Project Tycho. 2014. University of Pittsburgh [accessed on February 15, 2014]. Available at <https://www.tycho.pitt.edu/data/level2.php>
- Schlipkötter, U., and A. Flahault. 2010. “Communicable Diseases: Achievements and Challenges for Public Health.” *Public Health Reviews* 32: 90–119.
- Sensenig, A. L. 2007. “Refining Estimates of Public Health Spending as Measured in National Health Expenditures Accounts: The United States Experience.” *Journal of Public Health Management and Practice* 13 (2): 103–14.

- Smith, P. J., N. Jain, J. Stevenson, N. Mannikko, and N. A. Molinari. 2009. "Progress in Timely Vaccination Coverage among Children Living in Low-Income Households." *Archives of Pediatrics and Adolescent Medicine* 163: 462–8.
- U.S. Census Bureau. 2014. *Statistical Abstract of the United States: 2006*, 125th ed. [accessed on June 18, 2015]. Available at <http://www.census.gov/govs/state/>
- U.S. Department of Health and Human Services. 2015. *Office of Disease Prevention and Health Promotion. Healthy People 2020*. Washington, DC: U.S. Department of Health and Human Services [accessed June 6, 2015]. Available at <http://www.healthypeople.gov/>
- Walker, A. T., P. J. Smith, and M. Kolasa. 2014. "Reduction of Racial/Ethnic Disparities in Vaccination Coverage, 1995-2011." *MMWR Surveillance Summary* 63 (Suppl. 1): 7–12.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.

Table S1. Fixed Effects Regression Results for Pertussis Count Per State Per Year.

Table S2. Fixed Effects Regression Results for Rubella Count Per State Per Year.