NBER WORKING PAPER SERIES

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Working Paper 23923
http://www.nber.org/papers/w23923

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 2017

We would like to thank seminar participants at UNC Greensboro, UNC Chapel Hill Public Policy, the Bureau of Economic Analysis, Lafayette College and conference participants at the Western Economic Association, the Southern Economic Association, the Association for Public Policy Analysis and Management and the South Carolina Applied Micro Day for their helpful comments and suggestions. We also acknowledge financial support from a UNC Charlotte Faculty Research Grant. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 23923
October 2017
JEL No. I0,I12,J13

ABSTRACT

This paper examines the determinants of parental decisions about infant immunization. Using the exact timing of vaccination relative to birth, we estimate the effects of local pertussis outbreaks occurring in-utero and during the first two months of life on the likelihood of on-time initial immunization for pertussis and other immunizations. We find that parents respond to changes in perceived disease risk: pertussis outbreaks within a state increase the rate of on-time receipt of the pertussis vaccine at two months of age. This response is concentrated among low-socioeconomic status (SES) subgroups. In addition, we find that pertussis outbreaks increase the likelihood of immunization against other vaccine-preventable diseases. These spillover effects are almost as large the direct effects and are present only for vaccines that are typically given during the same visit as the pertussis vaccine, which suggests that healthcare access costs play an important role in parents' vaccination decisions.

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1. Introduction

The United States experienced a dramatic decline in the incidence of vaccine-preventable diseases over the 20^{th} century. This phenomenon, which resulted in substantial reductions in infant and child morbidity and mortality, is attributable in large part to the success of a large scale public health campaign to promote universal immunization (Centers for Disease Control and Prevention, 1999). Though overall rates of vaccine coverage in the U.S. have been high in recent decades, disparities in immunization coverage have persisted across socioeconomic and racial groups. In particular, children who are poor, black, and from low-income neighborhoods, and those with younger, less-educated, and unmarried mothers are more likely to fall behind the recommended schedule for childhood vaccines (Feemster, Spain, Eberhart, Pati and Watson, 2009; Luman, Barker, Shaw, McCauley, Buehler and Pickering, 2005). Meanwhile, concerns about perceived vaccine safety have led increasing numbers of parents to refuse or deliberately delay vaccination for their children. This uptick in active vaccination refusal is more pronounced among children who are white and have married, more-educated parents (Smith, Chu and Barker, 2004; Omer, Salmon, Orenstein, deHart and Halsey, 2009), and is clustered geographically, causing immunization rates to fall below herd-immunity levels in some areas and contributing to recent disease outbreaks (Feikin, Lezotte, Hamman, Salmon, Chen and Hoffman, 2000; Omer, Enger, Moulton, Halsey, Stokley and Salmon, 2008).

In this paper, we examine the determinants of parental decisions about infant immunization, with an emphasis on the roles of perceived disease risk and healthcare access costs. We focus on the timing of a child's *first* immunization doses for two reasons. First, the period encompassing pregnancy and early infancy is a time when many parents form opinions about vaccination and establish healthcare patterns for their children. Since most of the vaccines given to infants are part of a sequence, obtaining the first set of immunizations on time might help establish a routine with a care provider and make it more likely that subsequent vaccines will be received on time as well. Second, vaccine delay is an important contributor to disparities in vaccination rates along

socioeconomic and demographic dimensions. Many children, particularly those in disadvantaged families, will ultimately end up fully vaccinated by the time they start school but will experience substantial delays in their vaccination schedules during infancy and early childhood. As infants and toddlers have the highest likelihood of contracting vaccine-preventable diseases and of experiencing serious complications from them, vaccine delay has potentially-serious health implications (Feemster et al., 2009; Luman et al., 2005).

We begin by examining whether information about disease risk affects the on-time initiation of infant immunization. As rates of vaccine-preventable diseases in the US fell over the 20^{th} century, in some cases to near-zero, reductions in the perceived risk of illness among the population likely contributed to a decline in immunization rates. With the recent resurgence of some of these illnesses, the benefit from vaccinating has again increased, particularly for infants, who are the most vulnerable in an outbreak. If the public's awareness of this change has lagged the actual change, then information dissemination is a potential avenue by which policy might influence vaccination rates. In order to explore whether information about disease risk affects infant immunization, we construct outbreak indicators using weekly state-level counts of pertussis cases from the Center for Disease Control (CDC) and link them to child-level data from the National Immunization Survey. Using exact date of birth and the timing of each vaccine dose relative to birth date, we estimate the effects of pertussis outbreaks on the likelihood that the first dose of the diphtheria, tetanus, and pertussis (DTaP) vaccine is received within 75 days of life.

We find that pertussis outbreaks occurring in utero and between birth and two months of age increase the probability that the first pertussis immunization occurs on-time (within 75 days of birth). Splitting our sample along demographic and socioeconomic dimensions, we find that the increase in on-time vaccination is concentrated among minority children, children in low-income households, children with less-educated mothers, and children of unmarried mothers—groups most likely to be underimmunized for reasons related to limited healthcare access and other economic factors. We find no significant effects of outbreaks on the likelihood of on-time initiation of in-

fant immunization among children in non-poor families, white children, or children with college-educated mothers.

In the second part of our study, we explore whether pertussis outbreaks play a role in determining whether infants receive vaccines for other diseases on time. Estimating the "spillover" effects of pertussis outbreaks allows us to gain insight into the relative importance of different factors in influencing parental decisions about vaccination. First, we examine whether a pertussis outbreak increases on time receipt of other vaccines that are recommended to be given at the same time as the first DTaP dose (polio and Haemophilus influenzae type B (Hib)). We find that when a pertussis outbreak induces parents to vaccinate against pertussis, they also choose to obtain other vaccines offered at the same visit at nearly the same rate. As neither the perceived health benefits nor the expected health costs of other immunizations are likely to be affected by a pertussis outbreak, these effects may be attributable either to changes in attitudes about vaccination resulting from the outbreak or to changes in the time cost or other healthcare access costs that result from seeking out the pertussis vaccine. Next, we estimate the effect of pertussis outbreaks in utero on the likelihood that a child receives immunizations that are typically recommended to be received at *separate* visits from the initial DTaP dose—immunizations for hepatitis-B (recommended at birth), varicella, and measles, mumps, and rubella (MMR) (recommended at 12-15 months). We find that pertussis outbreaks occurring in utero or in the first two months do *not* result in an increase in receipt of these other vaccinations, and for some groups even decrease the likelihood that these vaccines are received during the recommended time window.

Our study complements contemporaneous work focusing on immunization of older children by Oster (2016) and Carpenter and Lawler (2017). Oster studies the effects of pertussis outbreaks on immunization rates of school-aged children using county-level data from twelve US states, and also finds that outbreaks increase immunization coverage. In contrast with our findings, Oster does not find spillover effects of pertussis outbreaks to immunization for other illnesses among school-aged children, which suggests either differences in the mechanisms driving the results between infancy

and later childhood, or differences in the relevant at-risk (under-vaccinated) populations between the two samples. Meanwhile, Carpenter and Lawler (2017) study the effects of state laws requiring a tetanus, diphtheria, and pertussis (TDaP) booster shot prior to middle school enrollment on immunization rates of middle school students, and find strong evidence of cross-vaccination spillovers. In particular, they find that TDaP mandates increased adolescent vaccination rates for meningococcal disease and human papillomavirus—vaccines that are also recommended for adolescents—with larger effects in low-SES subgroups. They do not discuss healthcare access as a possible reason for these spillover patterns, but their findings are consistent with our results for infants.

The results from this paper have several important implications for health policy. First, we show that disease outbreaks affect the on-time initiation of infant immunization. This implies that dissemination of information about disease risk has the potential to increase rates of immunization coverage among very young infants—the population with the highest risk of serious complications from illness. Second, the spillover effects of pertussis outbreaks on vaccination for other illnesses imply that policies that help disadvantaged families to overcome the costs associated with obtaining access to vaccines, including barriers to information, scheduling challenges, and transportation costs, are likely to be effective in reducing the risk of vaccine delay among low-SES families. Finally, we find evidence of substitution across sets of vaccines that are received at different visits among some disadvantaged subgroups. That is, for poor children, black children and children with single mothers, the increase in the likelihood of obtaining the first set of vaccines on time at two months is accompanied by a reduction in the likelihood of obtaining a separate set of vaccines typically offered between 12-15 months. This suggests an important role for educating families about the importance of obtaining *all* of the recommended vaccines and doses and further illustrates the importance of reducing barriers to regular and consistent healthcare.

2. Background

2.1. Cross-Sectional Correlates of Underimmunization

Because increasing immunization coverage has been a central goal of United States health policy for several decades, there exists a substantial literature, most of which is in the fields of public health and epidemiology, exploring patterns in U.S. immunization rates in the cross-section and over time. Rather than summarize the entirety of the existing body of research on this topic, we focus in this section on two overarching narratives that are relevant to our analysis.

First, many researchers have documented cross-sectional patterns in vaccination coverage that mirror patterns of socioeconomic inequality. In particular, black and Hispanic children, children from low-income families, and children with younger, less-educated, and unmarried mothers, are less likely to adhere to the vaccine schedule recommended by the Center for Disease Control (CDC) than the general population (Chu, Barker and Smith, 2004; Feemster et al., 2009; Guttmann, Manuel, Dick, To, Lam and Stukel, 2006; Luman, McCauley, Shefer and Chu, 2003; Smith et al., 2004). Discrepancies in vaccine coverage by socioeconomic status are especially pronounced when vaccine *delay* is taken into account, with substantial fractions of children in disadvantaged groups spending many months of their early childhood underimmunized. (Luman et al., 2005).

Lack of access to quality healthcare may be a significant barrier to on-time immunization of disadvantaged children, who are less likely in general to maintain a regular schedule of well-child visits and to utilize preventative care (Ronsaville and Hakim, 2000). Research has found that children with lower spatial accessibility to pediatricians are less likely to keep up with the CDC-recommended vaccine schedule (Fu, Cowan, McLaren, Engstrom and Teach, 2009; LeBaron, Massoudi, Stevenson and Lyons, 2001), as are children with low continuity in their healthcare provision (Luman et al., 2005). Under-immunization is also correlated with the receipt of care from a public health clinic or a less-experienced pediatric-care provider (Feemster et al., 2009; Guttmann et al., 2006). Convenience may also be an important factor, particularly among single-parent or two-earner families. A focus group study highlights a number of barriers to immunization

facing disadvantaged families, including scheduling challenges and transportation costs (Lannon, Brack, Stuart, Caplow, McNeill, Bordley and Margolis, 1995). In this paper, we label all of the costs associated with finding and visiting a quality healthcare provider, including non-monetary costs as "healthcare access" costs.

A second broad narrative in the literature on immunization relates to the recent increase in the share of children whose parents decline vaccines due to concerns about perceived vaccine safety (Omer et al., 2009). Researchers have typically identified this group by focusing on children who have received no vaccines at all (e.g. Smith et al. 2004) or children who have received non-medical exemptions from mandatory school vaccination laws (e.g. Salmon, Moulton, Omer, Patricia de-Hart, Stokley and Halsey 2005), though some parents choose to delay vaccines due to safety concerns rather than skipping them entirely. Correlational studies have found that unvaccinated and exempt children are more likely to be white, to come from higher-income families, and to have more-educated parents.

For policymakers, parents who opt out of vaccines due to concerns about health risks are a source of particular concern. While this group makes up a small share of the overall population, they are believed to contribute significantly to the spread of vaccine-preventable disease because they tend to be clustered geographically (Omer et al., 2008). For example, clustering of unvaccinated individuals is likely to have contributed to outbreaks of measles and pertussis in Colorado from 1987-1998 (Feikin et al., 2000) and a resurgence of pertussis in California in 2010 (Atwell, Van Otterloo, Zipprich, Winter, Harriman, Salmon, Halsey and Omer, 2013). Furthermore, interventions designed to educate parents about vaccine risks do not seem to have impacts on immunization behavior (Nyhan, Reifler, Richey and Freed, 2014; Sadaf, Richards, Glanz, Salmon and Omer, 2013).

In this paper, we exploit the differences in the demographic and socioeconomic composition of the two groups of children described above, along with detailed information on child and family characteristics available in the NIS data, to gain insight into potential policy avenues for increas-

ing vaccine coverage. In particular, we stratify the NIS sample by race/ethnicity, family income, maternal education, and parents' marital status to see whether the responsiveness of immunization timing to disease outbreaks is different for children who are most likely to delay or decline vaccines for economic reasons than for children who are more likely to delay or decline vaccines for reasons related to vaccine safety.

2.2. Conceptual Framework

Our interpretation of our empirical results is based on a simple conceptual framework, similar to that outlined by Oster (2016), in which parents make vaccine decisions by weighing perceived vaccine costs against perceived vaccine benefits. In this framework, the perceived benefit from vaccination for a particular disease depends on the perceived excess probability of contracting the disease in the absence of a vaccine. This perceived probability may in fact be greater than or less than the true value. However, we assume that a local disease outbreak (the external shock in our analysis) causes the perceived risk of illness to increase. For this assumption to hold, local disease outbreaks must be adequately publicized within a state, perhaps through the local news or by schools and medical providers. Oster (2016) provides supporting evidence on this front by documenting increases in both internet searches and local news articles related to pertussis following an outbreak.[1]

We make an important distinction between the expected health costs of vaccinating and health-care access costs associated with vaccination. The expected health costs of vaccination include injection pain and a small risk of complications from the vaccine. For some families, they may also include other concerns about vaccine safety. Access costs include the costs of obtaining information about vaccine recommendations, locating a provider, and scheduling an appointment, as well as copayments or fees, transportation costs, and time costs. For the substantial fraction of

[1] We also confirm that internet search activity increases during outbreaks defined in our data. The results of this analysis are available upon request.

families who already visit pediatric providers on a regular basis, the marginal costs of vaccination are likely to be minimal, as many of the access costs have already been incurred. However, the research findings summarized in the previous section suggest that these kinds of costs are significant barriers to immunization among disadvantaged families and thus may be important determinants of on-time vaccination for marginal children.

As Oster (2016) points out, this kind of cost-benefit framework can be consistent with the choice not to vaccinate. When the expected benefit of vaccinating (perceived disease risk) is very low, even small costs can outweigh it. What we expect, however, is that increases in perceived disease risk associated with local pertussis outbreaks should increase the share of children who receive the pertussis vaccine on time. If we are willing to assume that the utility cost of illness is comparable across groups (admittedly a strong assumption), the relative magnitudes of this direct response can provide insight into the size of the costs. In particular, the groups who have the largest response will be those with the lowest expected health and access cost barriers to immunization or those who update their beliefs about the benefits of vaccination the most.

Estimating spillover effects can provide insight into the mechanisms driving changes in vaccination behavior in response to disease outbreaks by helping us to distinguish the role of time costs and other healthcare access costs from the perceived health costs and benefits of vaccination. In particular, a pertussis outbreak should not change either the expected benefits or the perceived health costs of vaccination for other illnesses such as measles or polio. It may, however, encourage families to visit a vaccine provider in order to protect their children against pertussis. Once families have already incurred the access costs associated with a visit to a provider, the marginal costs of other immunizations that are offered at the same visit are lowered substantially. Therefore, any observed effects of pertussis outbreaks on take-up of other vaccines offered at the same time are likely to be due only to changes in healthcare access costs. Importantly, we should not expect this mechanism to increase take-up of vaccines that are offered at separate visits from the affected DTaP doses, as the monetary and time costs of additional visits are unaffected.

2.3. Related Studies

While a large body of research is dedicated to exploring the cross-sectional correlates of immunization, a smaller set of studies has used policy changes, direct interventions, and natural experiments to identify causal determinants of immunization. Among those that focus on childhood vaccines, the majority of these studies estimate the effects of mandatory school vaccination laws on immunization coverage among school-aged children (for example, Abrevaya and Mulligan 2011; Luca 2016). Notably, in estimating the effects of mandatory school vaccination laws on immunization of adolescent children, Carpenter and Lawler (2017) find substantial spillover effects from mandates for Tdap booster shots to immunization for meningococcal disease and human papillomavirus that are concentrated among low-SES households.

The work most closely related to our analysis is that of Oster (2016), who estimates the causal effects of county-level pertussis outbreaks on county-level immunization at kindergarten entry using data from 12 U.S. states. She finds effects that are substantial (a large outbreak decreases the share of kindergarteners who are not vaccinated for pertussis in the following year by about 20 percent). Oster (2016) shows increases in both local news coverage of pertussis and internet searches related to pertussis in the months following a local outbreak, which support the notions that information about outbreaks is disseminated widely and that individuals increase information-seeking behavior in response to an outbreak.

Other researchers have used natural experiments to study the role of financial costs in determining vaccine uptake. Joyce and Racine (2005) study the expansion of the State Children's Health Insurance Coverage Program during the 1990s and find that the proportion of poor and near-poor children who were up-to-date on their immunizations increased relative to the fraction of nonpoor children as a result of expanded public insurance coverage. Chang (2016) examines state mandates that private insurance plans cover recommended childhood vaccines. Exploiting variation across states and over time in the introduction of such mandates, she finds that reductions in the cost of vaccination increased the immunization rates for three vaccines—polio, measles-mumps-rubella,

and diptheria-tetanus-pertussis.

Our study makes several important contributions to the literature on the determinants of immunization. First, by focusing on the precise timing of vaccination in infancy, we are able to identify the effects of changes in perceived disease risk on immunization during the period in which parents are likely to be making the first immunization decisions for their children. Importantly, this is also the period during which the potential health costs of delayed immunization are the highest. Second, because we use individual-level data, we are able to explore differences in the response of immunization to changes in perceived disease risk along the same socioeconomic and demographic dimensions that are known to be correlated with vaccine coverage. Third, in studying the spillover effects of pertussis outbreaks on the timing of receipt of other vaccines, we are able to separately identify the role of vaccine access costs from the other potential mechanisms - changes in the perceived benefits or safety risks of immunization.

3. Data

In order to measure the effect of disease outbreaks on immunization behavior, we combine two datasets – one that contains individual level information on immunizations and another that contains information on the number of pertussis cases in each state and week.[2]

3.1. Outbreak Data

The outbreak data come from the Centers for Disease Control and Prevention (CDC)'s Morbidity and Mortality Weekly Reports (MMWR). Each week, the MMWR reports provide provisional counts of selected notifiable diseases for each state. The reports also include revised counts for the

[2]We have also collected disease count data for measles, mumps and varicella (Chicken Pox), but pertussis is the only one that is available throughout the entire time period. Infrequently reported diseases ($<$1000 cases reported in the previous year) are not reported by state, so our state level measure is not available for all diseases in all years. For this reason, and because there is significantly more variation in exposure to pertussis outbreaks, we chose to focus on pertussis.

prior year. Using those weekly reports, we compiled a database that covers the years 1996-2014 and includes both the provisional counts of pertussis cases for each state and week and the revised counts.

In order to examine whether or not parents respond to local outbreaks of a vaccine-preventable disease, we first need to define what an "outbreak" is. Our primary measure of an outbreak is an indicator for whether the four week moving average of weekly pertussis cases is above the 95^{th} or 99^{th} percentile of disease counts within a state over time, where percentile thresholds are calculated using non-zero weekly counts. Our choice to focus on 95^{th} or 99^{th} percentile outbreaks is informed by an analysis of internet search data from Google Trends. In particular, we find that in weeks where the count is above either the 95th or the 99th percentile, search activity for the term "whooping cough" significantly increases within a state. Although we also find increases in search activity with lower thresholds, the increases are largest at these higher thresholds, and the results are robust to alternative specifications.[3] We use a moving average to smooth out any lumpiness in reporting. Inspection of the data suggests that states may occasionally skip reporting in a week, and effectively report multiple weeks at once. Using the four week average helps us avoid accidentally counting those weeks as being above the threshold.

Figure 1 gives an example of an outbreak based on this definition. The top left panel displays the 4 week moving average of the number of cases, by week, in Idaho, and the horizontal line gives Idaho's 99^{th} percentile threshold for pertussis cases (27.75). During 1997, Idaho had a number of weeks above its 99^{th} percentile. At the same time, we can see that in three nearby states, there weren't any weeks above the threshold. Figure 2 shows the same four states in 2007. During that year only Colorado experienced an outbreak. Table 1 gives the 95th and 99th percentile thresholds for each state.

It is important to note that in many years, cumulative counts are provided in the published MMWR reports, rather than counts for the current week. For consistency, we always use the

[3] Results and additional details are available upon request.

cumulative counts. Subtracting the previous week's count from the current week sometimes results in a negative number of cases. This happens for at least two reasons. First, the reported numbers are preliminary counts, and the number of cases in previous weeks is often revised over time. If the number of cases in a previous week is revised down, it will decrease the cumulative number of cases reported in the current week, but there is no way of looking back to see which week was revised until the following year. We do not make any data corrections in cases where the count is greater than -3. We prefer to use the numbers that were most likely to have been reported in the news, rather than using the numbers that are released a year later. Second, in a small number of cases, there is an obvious data entry mistake.[4] Usually this shows up as a cumulative case count of zero in the middle of a year, followed by a return to normal in a subsequent week, or an unusually large increase followed or proceeded by a similarly sized decrease. For weeks where this results in a count that is less then -3, we apply the following smoothing procedure: we take the cumulative case count from three weeks after the questionable week, subtract the cumulative count from three weeks before and divide by 7. In nearly all cases, this captures both the week with what looks like a data entry mistake, as well as the subsequent correction. The result is that we have an accurate average number of cases over the 7 week period, but do not capture any variation in cases within that period.[5]

3.2. Immunization Data

The immunization data come from the National Immunization Survey (NIS). The NIS is sponsored by the CDC, and it is used to generate official estimates of vaccine coverage at the state and national level. The study collects information on randomly selected households with children be-

[4] Less than 0.5% of cases fall into this category.

[5] Additionally, there are 7 cases where a seemingly obvious data entry was made, but our smoothing process is not enough to fix it. In 4 cases, the mistake was similar to the one described above, but the corresponding week was more than 3 weeks away. In these cases, we fixed the data by hand. In 3 cases, there was no obvious correction week. In those cases, we used the revised number from the following year's report. More details are available upon request.

tween the ages of 19 months and 35 months via a household telephone survey and a mail survey of vaccination providers. The data are available from 1995 through 2012 and include information on household demographics, as well as the types of vaccinations received and the child's age in days at vaccine receipt.[6] We use the restricted use version of the NIS, which includes each child's state of residence and exact date of birth. This allows us to create a variable that indicates whether or not a pertussis outbreak occurred in a child's state while they were in utero or during their first two months of life. Our primary outcome of interest is an indicator for whether or not an individual received their first DTaP immunization on time. The recommended age is two months (61 days), and we allow for a two week grace period to account for appointment scheduling conflicts, for a total of 75 days. We also examine whether an increase in on-time receipt of the DTaP vaccination spills over to other two-month immunizations, and consider a variety of other immunization outcomes, including whether a child received a hepatitis-B vaccine at birth, whether a child received vaccines for MMR and varicella by 15 months, and DTaP coverage by 19 months of age.

Table 2 displays the summary statistics for the immunization and demographic variables in the NIS. Approximately 77 percent of children receive their first DTaP immunization by 75 days. The percentage of children receiving their other 2-month immunizations on time is similar (Hib, Polio). There is a long right tail in the distribution, however, with an *average* age of first DTaP of 77 days, but a median of 64 and a maximum of 1210.[7] The percentage of children receiving later immunizations on time is lower than for the 2-month immunizations. We see that 55% of children receive their varicella vaccination by 15 months (470 days) and 70% of children receive their first measles containing vaccine by 15 months. Approximately 68% of children have received the recommended four doses of DTaP by 19 months and, on average, they have received 3.6 doses by that time.

[6] Data for 2004 is not available in the restricted use version of the NIS dataset.

[7] In the 1995, 1996, 1997 and 1998 surveys, Age in Days is recoded as -1 if it is recorded as anything less than zero. This is true for less than 0.2% individuals.

4. Estimation Strategy

We use a fixed effects model to estimate the effect of disease outbreaks on the propensity for children to be immunized at different points in time. The model includes month of birth and state fixed effects so that our identification relies on variation in the timing of outbreaks across and within states. In other words, we estimate whether birth cohorts that experience a very high number of pertussis cases relative to other birth cohorts in the same state, are more likely to be immunized on time, controlling for aggregate (nationwide) variation in immunization across birth-cohorts.

Our preferred estimation specification is:

$$\text{DTP75}_{isw} = \alpha + \beta\ \textbf{Outbreak}_{sw} + \omega\ X_{isw} + \gamma_s + \gamma_m + \epsilon_{isw} \quad (1)$$

where DTP75_{isw} is an indicator for whether or not individual *i*, living in state *s*, and born in week *w* received their first DTaP immunization by the time they are 75 days old.[8] $\textbf{Outbreak}_{sw}$ is a variable that indicates exposure to a disease outbreak during the one-year period spanning the ten months prior to birth and the two months after birth, for a child born in week *w* and in state *s*. Throughout the paper, we show results for both 95th percentile and 99th percentile outbreaks, where the outbreak cutoffs are defined relative to own-state pertussis counts.[9] X_{isw} is a vector of individual child characteristics that includes birth order, child gender, child race and ethnicity, maternal education, and family poverty status, and γ_s and γ_m are fixed effects for state and month-by-year of birth. Standard errors are clustered by state and the regressions are weighted using NIS survey weights. β is the regression coefficient of interest, as it represents the effect of an outbreak in utero or early infancy on the probability of on-time immunization at two months of age.

[8] The recommended age for this particular immunization is two months, or 61 days. We use 75 days to allow for typical appointment scheduling conflicts.

[9] One concern with using a single cutoff to define outbreaks is that the estimated treatment effects will be attenuated by the inclusion of smaller outbreaks in the control group. However, we have estimated results including multiple percentile cutoffs together (50-74, 75-89, 90-94, 95-98, and 99) and found that the 95th and 99th percentile results were not very different. This suggests that the treatment effects we are estimating are particular to major (95th and 99th percentile) outbreaks. These results are presented in Appendix Table A3.

We begin by testing sensitivity of the regression estimates for the full NIS sample to the inclusion of demographic controls, state fixed effects, and time fixed effects. In the remaining tables, we estimate our preferred specification (as described above) separately for a set of subgroups defined by poverty status, child race and ethnicity, and mother's education and marital status. In others, we replace the key left-hand-side variable (DTP75) with alternative immunization outcomes, including indicators for other 75 day immunizations, indicators for receiving a hepatitis B vaccine at birth, indicators for receiving varicella and MMR vaccines by 15 months of age, and DTaP coverage by 19 months of age.

5. Results

5.1. Effect of Pertussis Outbreaks on DTaP by 75 Days

Our first question is whether information about disease risk directly affects the timing of infant vaccination for the disease in question. In Table 3, we show the estimated effects of experiencing a pertussis outbreak during the past 12 months on the likelihood that an infant receives his or her first DTaP vaccine dose by 75 days of age and test the sensitivity of this result to our choice of model and outbreak variable. As discussed in Section 2.2, we expect that an outbreak should increase the perceived benefits of vaccinating by increasing the perceived risk of illness. The estimates in Table 3 show that this is indeed the case: a pertussis outbreak increases the likelihood that a child receives his or her first DTaP dose on time by 0.9 to 1.3 percentage points. When scaled by the share of children who do not get this vaccine on time in the full sample (21.2 percent of children), these values imply that an outbreak reduces the fraction of children who delay or miss their first DTaP immunization by 4.4 to 6.1 percent. While the magnitude and precision of the coefficients change a bit with the addition of demographic controls and state and time fixed effects, the coefficients are generally similar across columns and across the two panels, which present the results separately for a 95th percentile outbreak cutoff and a 99th percentile outbreak cutoff.

Next, in Table 4, we explore whether the results for the full NIS sample mask heterogeneity

along demographic and socioeconomic dimensions. In particular, we investigate whether subgroups in which children are most likely to delay or miss immunization due to cost or limited access to quality healthcare (low-SES groups) respond differently from subgroups in which children are more likely to delay or miss vaccines due to parental concerns about vaccine safety (more often families with white, college-educated parents). To do this, we split the sample by poverty status, child race and ethnicity, mother's education, and mother's marital status.

Before examining the regression results, we first verify that the summary statistics for on-time receipt of the first DTaP dose match the patterns that have been established in the literature. The row titled "Y Mean" near the bottom of Table 4 provides the weighted mean for the subgroup listed at the top of the column. For example, the means at the bottom of the second and third columns tell us that 82.2% of children above the poverty line receive their first DTaP immunization by the time they are 75 days old, while only 71.4% of children below the poverty line do. Across the remaining columns, the discrepancy in on-time immunization rates between high- and low-SES families is apparent for each set of subgroups: Black and Hispanic children, children of less-educated mothers, and children of unmarried mothers all have lower rates of immunization. These patterns, which are consistent with those documented in the existing literature, highlight an important point—while change in vaccination behavior among white, college-educated families might be contributing to the recent decline in immunization rates, low-SES children still make up a large portion of the under-immunized child population.[10]

The regression results in Table 4 show that the response to disease outbreaks is larger among the subgroups that have the lowest baseline rates of on-time immunization and are most likely to be underimmunized for reasons related to healthcare access costs—the low-SES subgroups. In this table, each column presents the results of estimating Equation 1 separately for the group listed

[10]Coefficients on the demographic control variables from the regressions in Table 3 are presented in Appendix Table A1. These coefficients, which represent regression-adjusted correlations between socioeconomic and demographic characteristics and on-time DTaP receipt, are consistent with the raw differences in means, with one exception: when simultaneously controlling for race and ethnicity, poverty status, mother's education and marital status, as well as child gender and birth order, Hispanic children actually have higher immunization rates than white children.

at the top of the column (including all control variables except for the stratifying variable). The number displayed in italics below each coefficient's standard error is the coefficient expressed a percentage of the portion of that group that is *not* vaccinated on time (one minus the mean listed at the bottom of the table). We find that children in families below the poverty line (22 percent of the NIS sample) are 3 to 3.4 percentage points more likely to obtain their first dose of DTaP on time if they experience a pertussis outbreak, which is equivalent to a 10.5 to 11.9 percent reduction in the size of non-vaccinating population at that age. We find effects of similar magnitude among black and Hispanic children, with estimates ranging from 9 to 12 percent of the relevant non-vaccinating population in each subgroup. The largest treatment effect is seen for the group of children whose mothers have less than a high school education—a 14.4 percent effect. Finally, there is evidence that children of single mothers are more likely to get vaccinated on time after an outbreak than children of married mothers, though differences by marital status are not as large.

The results in Table 4 show that the overall effects presented in Table 3 are masking substantial heterogeneity in the response to outbreaks across socioeconomic status. The estimates suggest that educational attainment may be a particularly important source of disparities across groups, since the coefficients for the group of children whose mothers have not graduated from high school are larger than for any of the other subgroups. Notably, in the results shown in Table 4, we find no evidence of any effects of pertussis outbreaks on the likelihood of obtaining the first pertussis vaccine on time among the non-poor, white, and college-educated groups. In fact, the coefficients for these groups, though not significant, are slightly negative in Panel B, suggesting a possible role for reverse causality in that association. In particular, for birth cohorts in which mothers in more-advantaged groups are less likely to vaccinate, the risk of experiencing an extreme outbreak is slightly higher. This raises a concern about our identification strategy: if differences across birth-week cohorts in the likelihood of experiencing a pertussis outbreak are associated with other unobservable changes (in attitudes about vaccination, for example) that are related to the likelihood of on-time vaccination, our results will be biased. Since the bias is most likely to be negative, this

is unlikely to explain the significant positive coefficients we find in Table 4. Nonetheless, we conduct a falsification test in which we include outbreaks that occur in months 3-6, after the two-month immunizations. Results, presented in Appendix Table A2, show no significant association between received the first DTaP dose on time and subsequent outbreaks.

5.2. Spillover Effects of Pertussis Outbreaks

Next, we turn our attention to the spillover effects of pertussis outbreaks onto immunization for other illnesses. As discussed in Section 2.2, the extent of spillover effects can help to distinguish the roles of factors such as the costs of obtaining information, financial costs, transportation costs, and time costs (grouped together here and labeled as "access costs") in the decision whether to obtain a particular vaccine from the effects of a change in the perceived risk of illness. The idea is that an outbreak of pertussis should not affect either the risk of contracting other diseases or the perceived health and safety risks of vaccines for other diseases. Instead, as we have documented in the previous two sections, an outbreak of pertussis increases the likelihood that low-SES families seek out and obtain the DTaP vaccine for their infants. In this way, pertussis outbreaks might generate new interactions with medical providers that otherwise wouldn't have occurred, reducing the access costs associated with obtaining vaccines that are offered at the same time as the DTaP vaccine. If this is the case, we should expect to see spillover effects (1) only for the subgroups that had significant direct effects, (2) specifically for subgroups with lower frequency of routine wellness care, and (3) only for vaccines that can be given at the same time as the first DTaP dose.

To determine which factors affect parents' decisions to immunize their infant, we first estimate the effects of experiencing a pertussis outbreak in the previous year on the likelihood that children receive vaccinations for polio and Haemophilus influenzae type b (Hib)—two immunizations that are also recommended at two months of age—by 75 days. In Table 5, we present spillover effects for 99th percentile outbreaks (results for 95th percentile outbreaks, presented in Appendix Table A4 are similar). We find that a pertussis outbreak results in significant increases in the likelihood

that infants are immunized on-time for polio and hib, with effects concentrated among the same low-SES groups that had the largest direct effects. The results are only slightly smaller in magnitude than the direct effects shown in Table 4. For example, among poor children, the coefficient represents a 10.9 percent reduction in the non-vaccination rate for polio and a 9.3 percent reduction in the non-vaccination rate for hib. For infants whose mothers have less than a high school degree, the effects for polio and hib are both equivalent to 12.5 percent of the non-vaccination rate for that group. These findings suggest that once children in low-SES groups are visiting a vaccine provider to obtain a pertussis shot, they are also likely to obtain other shots that are offered at the same visit. This suggests that either health access costs are an important barrier to immunization, or that experiencing a local outbreak of any disease might change parents' attitudes toward immunization more generally, or cause medical providers to take a stronger pro-immunization stance in the periods following disease outbreaks.[11]

In order to distinguish between the possible mechanisms driving the spillover effects in Table 5, we turn our attention to vaccines that are typically received separately from the first DTaP dose: the first dose of hepatitis-B, which is recommended in the hospital at birth, and the first doses of MMR and varicella, both of which are recommended at 12-15 months. Receipt of the first Hepatitis-B dose at birth is the cleanest test of the potential alternative mechanisms described above, since the CDC recommendation about when this dose should be given is unambiguous and it is recommended within the same general timeframe as our key outcome variables (early infancy). With MMR and varicella, the potential mechanisms are more complicated and interpretation is a bit more challenging. For these two vaccines, the CDC recommendation about when they should be received is ambiguous—the first dose is recommended between 12 months and 15 months.

[11] It is also important to note that in recent years, more options for combination vaccines have become available. It could be that we observe spillover effects simply because the DTaP immunization is given in the same injection as the others. If this is the case, it might change how we think about the "decision" to get additional vaccinations at the same visit. Before 2009, there was a combination available that bundled the polio vaccination with DTaP, but no combination that included both DTaP and hib. We check whether there are any differences in spillovers to polio vs. hib pre-2009, before hib was available as a combination. We find no difference, suggesting that the observed spillovers are not being driven by combination shots. These results are available upon request.

They are typically given at 12 months, when there is no DTaP dose given. However, if a child does not obtain them at 12 months, they can be given 15 months, which is when the 4th DTaP dose is typically given. Here, our outcome variables are indicators for receiving each shot by 15 months of age, or by the end of the CDC recommendation window. The expected effects of a pertussis outbreak that occurs in utero or in the first two months of life on these later immunizations will incorporate changes in vaccination attitudes overall that result from the outbreak, changes in the likelihood of attending the twelve and fifteen month visits, and changes in the likelihood of getting the immunizations at each visit.

Estimates of the spillover effects from pertussis outbreaks to the hepatitis-B, MMR, and varicella vaccines are presented in Table 6. In Panel A, which shows the effects on hepatitis-B, the outbreak indicator only covers the six month period prior to birth, as the outcome in question occurs at the time of birth. In Panels B and C, which show the effects on 15 month immunizations, we control for later outbreaks as well, including an indicator for outbreaks occurring between 3 and 15 months of life. Across all three panels, we find no evidence that early-life pertussis outbreaks generate the same positive spillover effects that we saw in the previous table for vaccines that are recommended to be received separately from DTaP doses. In fact, we find the opposite: pertussis outbreaks seem to generate substitution across immunizations. For hepatitis-B, the point estimates for the poor, black, less-than-high school, and unmarried subgroups are equivalent to 5 to 7 percent reductions in the likelihood of receiving the first immunization dose at the time of birth, though only one of these estimates is statistically significant. We find evidence of even stronger substitution for some groups with the fifteen month vaccines. In particular, children of unmarried and black mothers are substantially less likely to obtain both MMR and varicella on time if they experienced a pertussis outbreak in utero or in early life.

Taken together, our results suggest that low-SES groups are constrained with respect to their health care utilization, and that this constraint is affecting infant immunization coverage in these groups. Among poor, less-educated, minority, and unmarried groups, a pertussis outbreak in-

creases the likelihood of getting the first set of vaccines on time—not just pertussis, but all vaccines that are recommended at two months of age. However, for some families, these increases are accompanied by a reduction in the likelihood that later vaccines are received on-time. Though we can only speculate about the reasons for this, the fact that the substitution effects are particularly strong for the children of unmarried mothers and for the children of black mothers, who are substantially more likely to be unmarried and also more likely to work than mothers in any of the other groups, suggests that it may be driven by families experiencing time constraints.

5.3. Long-run Immunization Effects

Finally, we explore whether on-time initiation of pertussis immunization has an effect on the number of pertussis doses that are received and whether children are ultimately up-to-date on their pertussis sequence. Table 7 shows the effect of a pertussis outbreak during the 12 month periods beginning 6 months before birth and at 6 months old on immunizations received by 19 months (we shift the timing of the outbreak shocks by a few months in order to better cover all outbreaks experienced in infancy). The results in Panel A show that an outbreak during either of those time periods increases the number of DTaP vaccinations received by 19 months, though only slightly. By that time, the full 4 dose sequence should be completed. The mean doses for each subgroups range between 3.4 and 3.7, and all but one of the coefficients translates to less than 1 percent of the relevant subgroup mean. Interestingly, the increases in the total number of vaccine doses is seen not only in the low-SES subgroups but also in the *more* advantaged groups. Along with the positive cross-vaccine spillovers seen for pertussis outbreaks occurring between 3 and 15 months of age in Table 6, these results suggest that non-poor, white, and college-educated families do respond somewhat to outbreaks, but do so by adjusting the timing of later vaccine doses rather than by accelerating the timing of the first dose.

Panel B displays the results for an indicator for whether a child has received all four recommended DTaP immunizations by 19 months of age. Here, we see that while a pertussis outbreak

during the period six months before to six months after birth has a positive, and often statistically significant, effect on being up-to-date, a later outbreak does not. This suggests that an earlier outbreak, which causes an on-time *initiation* of the sequence also encourages parents to make sure their children are fully up to date by 19 months. However once parents delay, they are unable to complete the sequence on time, even if a later outbreak encourages them to initiate the sequence earlier than they would have in the absence of an outbreak.

6. Conclusions

Improving early childhood vaccination rates is an important policy goal to ensure the health of American children. A growing number of children are under-vaccinated, either for economic or personal reasons. The goal of this study has been to understand how changes in perceived disease risk and access costs alter parents' decisions to initiate vaccination for their infants. By assessing the effects of pertussis outbreaks during pregnancy and early infancy on the procurement of vaccines that protect agains pertussis, as well as those that protect against different diseases, we are able to separately identify the roles of perceived disease risk and access costs in the decision to vaccinate. For children whose mothers have not graduated from high school, we find that a pertussis outbreak while a child is in utero increases the likelihood of obtaining the first pertussis vaccination on-time by more than four percentage points—the equivalent of a 14.4 percent reduction in the non-vaccinated population. Similarly, responses are largest for children below the poverty line, black and hispanic children and those whose mothers are unmarried. Since low-income, less-educated, and minority families are very responsive to changes in their perceived disease risk, these populations might be effectively targeted with policy efforts that improve information about the benefits of vaccination.

We also find that when parents respond to a pertussis outbreak by getting their child immunized against pertussis, they often bundle that immunization with others that can be given at the same time. However, for some groups, this increase in immunization is accompanied by a decrease in

the likelihood of getting other immunizations that are typically recommended to be received at separate visits from the first DTaP dose. These patterns reveal the significant role that access costs play in influencing parental decisions about immunization, particularly for the populations who are likely to be time- and resource-constrained. They are perhaps not surprising, as full immunization requires frequent visits to the doctor. In fact, perfect compliance with the CDC's recommended vaccination schedule for infants and toddlers requires as many as six separate interactions with medical providers—at birth, two months, four months, six months, 12 months, and 15 months. These visits can involve monetary costs, time costs, and transportation costs. Policies that help eliminate these costs such as community-based health centers or free neighborhood vaccination clinics can help facilitate vaccine initiation and follow-up for this population. The literature on improving attendance at prenatal visits may provide insight about how to facilitate well-child visits for the same population.

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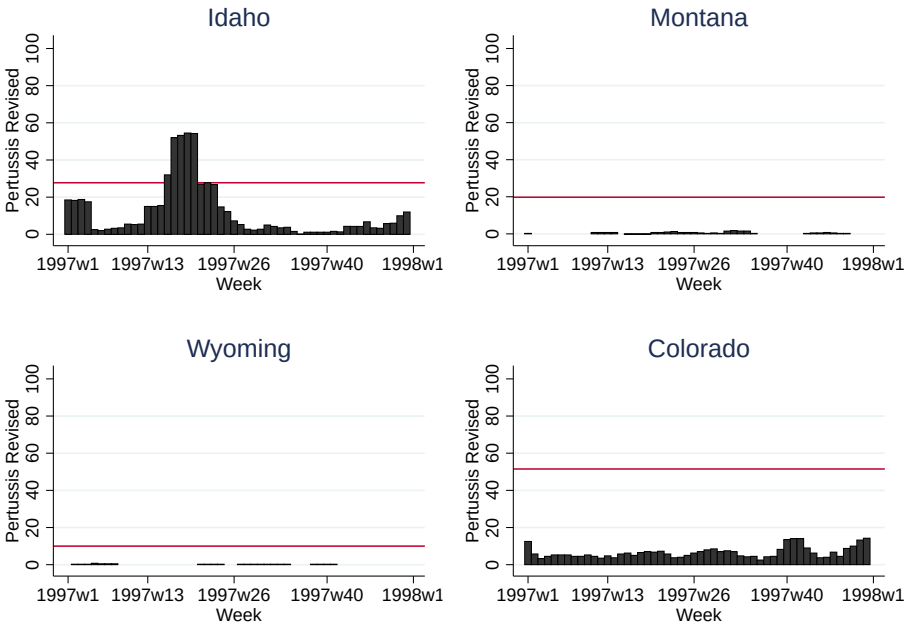
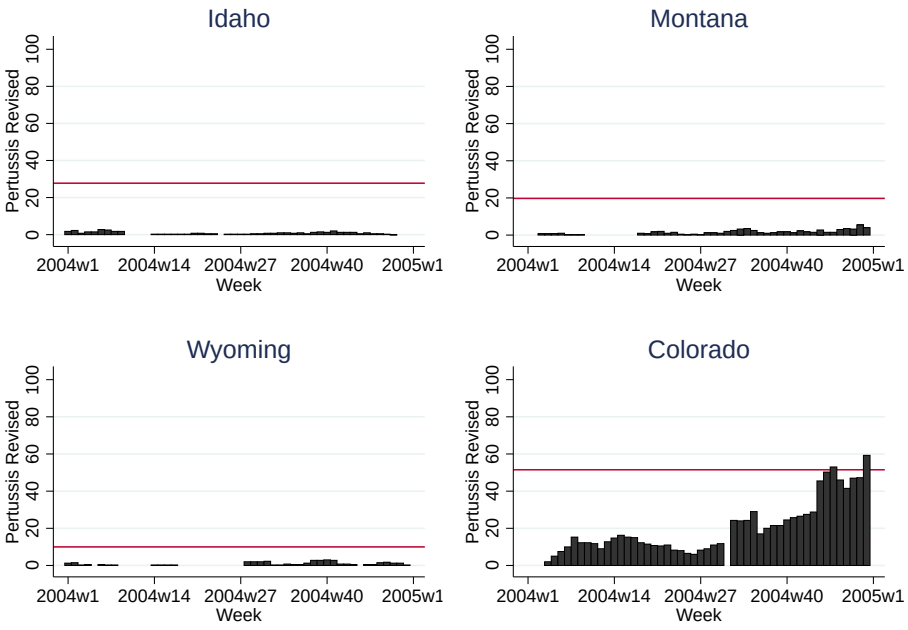
Figure 1: Pertussis Cases in 1997



Notes: This displays the 4 week moving average of the number of pertussis cases per week in a sample of four states. The horizontal line gives the 99th percentile for the 4 week moving average of weekly cases in each state. Data come from the Centers for Disease Control and Prevention's Morbidity and Mortality Weekly Reports.

Figure 2: Pertussis Cases in 2004



Notes: This displays the 4 week moving average of the number of pertussis cases per week in a sample of four states. The horizontal line gives the 99th percentile for the 4 week moving average of weekly cases in each state. Data come from the Centers for Disease Control and Prevention's Morbidity and Mortality Weekly Reports.

Table 1: Outbreak Thresholds

	95^{th}	99^{th}		95^{th}	99^{th}
AL	5.75	11	**MT**	10.5	19.75
AK	7.25	11	**NE**	7.25	15.25
AZ	23.5	56	**NV**	3	4.75
AR	11.5	22.75	**NH**	6.25	9.25
CA	70	116.5	**NJ**	8.5	11.5
CO	29.5	51.5	**NM**	7.5	12.25
CT	4	10	**NY**	41	56.5
DE	1.75	2.75	**NC**	8.75	19.25
DC	0.75	1.25	**ND**	12.25	79
FL	10.25	14.75	**OH**	34.25	58.25
GA	6	10.5	**OK**	5.25	10.75
HI	3.5	5	**OR**	15	21.25
ID	10.5	27.75	**PA**	21.5	34.25
IL	28.75	55.5	**RI**	3.5	9.25
IN	13.25	21.75	**SC**	9.5	15.5
IA	19.75	34.5	**SD**	6	15.5
KS	12.5	22	**TN**	6	8
KY	7.75	11.75	**TX**	66.5	101.5
LA	3.5	6.5	**UT**	17.25	33
ME	4.75	8	**VT**	8.75	15
MD	6	9.75	**VA**	9.5	23.25
MA	47.75	80.5	**WA**	24.75	40.75
MI	24.5	44	**WV**	3.5	7.5
MN	29.5	70	**WI**	31.25	176.75
MS	3.5	11.5	**WY**	3.25	10
MO	25.5	35			

Notes: This table gives each state's 95th and 99th percentile for weekly pertussis cases. Data come from the Centers for Disease Control and Prevention's Morbidity and Mortality Weekly Reports.

Table 2: Summary Statistics

Variable	Observations	Mean	SD	Min	Max
2-Month Immunizations					
DTaP by 75 days	310874	0.773	0.419	0	1
Hib by 75 days	310874	0.760	0.427	0	1
Polio by 75 days	310874	0.758	0.428	0	1
First DTaP, Age in Days	306221	77.300	61.600	-1	1210
First Hib, Age in Days	305653	79.600	68.200	-1	1235
First Polio, Age in Days	304276	77.200	58.100	-1	1246
Other Immunizations					
Varicella by 470 Days	310874	0.551	0.497	0	1
MCV by 470 Days	310874	0.701	0.458	0	1
UTD on DTaP by 19 months	310874	0.676	0.468	0	1
# DTaP by 19 months	310874	3.560	0.795	0	4
Demographic Variables					
Black	310874	0.152	0.359	0	1
White	310874	0.582	0.493	0	1
Hispanic	310874	0.266	0.442	0	1
Poor	284424	0.287	0.452	0	1
HS Degree	310874	0.527	0.499	0	1
College Degree	310874	0.287	0.452	0	1
First Born	275408	0.419	0.493	0	1
Male	310874	0.513	0.500	0	1

Notes: This table gives summary statistics for the National Immunization Survey (NIS). Means are weighted using survey weights. In the 1995, 1996, 1997 and 1998 surveys, "Age in Days" is recoded as -1 if it is recorded as anything less than zero. This is true for less than 0.2% individuals.

Table 3: Effects of Pertussis Outbreaks on DTaP Immunization by 75 Days

	(1)	(2)	(3)	(4)	(5)
95th Percentile Cutoff					
Pertussis Outbreak	0.009*	0.011**	0.010**	0.009*	0.011*
(12 Months)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
99th Percentile Cutoff					
Pertussis Outbreak	0.009	0.013**	0.012*	0.009	0.010
(12 Months)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)
Individual Controls	No	Yes	Yes	Yes	Yes
State Fixed Effects	No	No	Yes	Yes	Yes
Year Fixed Effects	No	No	No	Yes	No
Month-Year Fixed Effects	No	No	No	No	Yes
Y Mean	0.785	0.788	0.788	0.788	0.788
Observations	175617	165843	165843	165843	165843

Notes: The key explanatory variable is an indicator for having experienced an outbreak of pertussis in the state of birth during the period starting 10 months prior to birth and ending 2 months after birth. This variable is equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table 4: Effects of Pertussis Outbreaks on DTaP Immunization by 75 Days, Subgroups

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
95th Percentile Cutoff											
Pertussis Outbreak	0.011*	0.002	0.030**	0.002	0.033**	0.021**	0.042**	0.005	0.001	0.018	0.008
(12 Months)	(0.005)	(0.004)	(0.012)	(0.006)	(0.015)	(0.010)	(0.020)	(0.005)	(0.005)	(0.011)	(0.005)
	0.0519	*0.0112*	*0.1049*	*0.0106*	*0.1236*	*0.0905*	*0.1438*	*0.0219*	*0.0074*	*0.0657*	*0.0437*
99th Percentile Cutoff											
Pertussis Outbreak	0.010	-0.003	0.034***	-0.003	0.028**	0.028**	0.042*	0.008	-0.004	0.022*	0.006
(12 Months)	(0.007)	(0.005)	(0.011)	(0.006)	(0.013)	(0.013)	(0.023)	(0.007)	(0.006)	(0.012)	(0.006)
	0.0472	*-0.0169*	*0.1189*	*-0.0160*	*0.1049*	*0.1207*	*0.1438*	*0.0351*	*-0.0294*	*0.0803*	*0.0328*
Y Mean	0.788	0.822	0.714	0.812	0.733	0.768	0.708	0.772	0.864	0.726	0.817
Observations	165843	129802	36041	111214	19847	34782	18477	74165	73201	40644	125199

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variable is an indicator for having experienced an outbreak of pertussis in the state of birth during the period starting 10 months prior to birth and ending 2 months after birth. This indicator is equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table 5: Spillover Effects on Other Immunizations Received at the Same Visit as the First DTaP Dose, 99th Percentile

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: Polio by 75 Days											
Pertussis Outbreak	0.008	-0.004	0.032***	-0.004	0.023*	0.025*	0.037	0.007	-0.005	0.019	0.005
-10m to 2m	(0.006)	(0.004)	(0.011)	(0.006)	(0.012)	(0.015)	(0.023)	(0.006)	(0.006)	(0.013)	(0.005)
	0.0346	*-0.0198*	*0.1088*	*-0.0188*	*0.0836*	*0.1029*	*0.1246*	*0.0288*	*-0.0292*	*0.0671*	*0.0242*
Y Mean	0.769	0.798	0.706	0.787	0.725	0.757	0.703	0.757	0.829	0.717	0.793
Observations	165843	129802	36041	111214	19847	34782	18477	74165	73201	40644	125199
Panel B: Hib by 75 Days											
Pertussis Outbreak	0.011*	0.002	0.028**	-0.001	0.019	0.031***	0.038*	0.011*	-0.004	0.021*	0.008
-10m to 2m	(0.006)	(0.005)	(0.011)	(0.006)	(0.011)	(0.011)	(0.021)	(0.006)	(0.006)	(0.011)	(0.005)
	0.0489	*0.0105*	*0.0927*	*-0.0050*	*0.0674*	*0.1255*	*0.1250*	*0.0456*	*-0.0268*	*0.0729*	*0.0408*
Y Mean	0.775	0.810	0.698	0.801	0.718	0.753	0.696	0.759	0.851	0.712	0.804
Observations	165843	129802	36041	111214	19847	34782	18477	74165	73201	40644	125199

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table 6: Spillover Effects on Immunizations Received at Separate Visits From the First DTaP Dose, 99th Percentile

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: Hepatitis B at Birth											
Pertussis Outbreak	-0.004	0.008	-0.028*	-0.004	-0.023	-0.003	-0.024	0.005	-0.003	-0.019	0.002
-6m to 0m	(0.009)	(0.013)	(0.015)	(0.011)	(0.024)	(0.014)	(0.015)	(0.013)	(0.012)	(0.012)	(0.011)
	-0.0092	*0.0175*	*-0.0720*	*-0.0089*	*-0.0575*	*-0.0071*	*-0.0593*	*0.0118*	*-0.0063*	*-0.0485*	*0.0044*
Y Mean	0.564	0.543	0.611	0.550	0.600	0.575	0.595	0.577	0.525	0.608	0.544
Observations	181708	142243	39465	121471	22335	37902	20356	81982	79370	44926	136782
Panel B: Measles Containing Vaccine by 15 Months											
Pertussis Outbreak	-0.008	-0.002	-0.022**	-0.001	-0.042**	-0.011	-0.006	-0.013	-0.001	-0.032***	0.001
-10m to 2m	(0.006)	(0.006)	(0.009)	(0.007)	(0.020)	(0.010)	(0.012)	(0.009)	(0.005)	(0.010)	(0.007)
	-0.0315	*-0.0080*	*-0.0837*	*-0.0037*	*-0.1505*	*-0.0524*	*-0.0232*	*-0.0492*	*-0.0043*	*-0.1176*	*0.0041*
Pertussis Outbreak	0.012**	0.013*	0.010	0.020***	0.005	0.002	0.030*	0.009	0.008	0.025*	0.004
3m to 15m	(0.006)	(0.007)	(0.009)	(0.007)	(0.012)	(0.013)	(0.017)	(0.008)	(0.009)	(0.013)	(0.004)
	0.0472	*0.0520*	*0.0380*	*0.0743*	*0.0179*	*0.0095*	*0.1158*	*0.0341*	*0.0342*	*0.0919*	*0.0163*
Y Mean	0.746	0.750	0.737	0.731	0.721	0.790	0.741	0.736	0.766	0.728	0.755
Observations	153909	120842	33067	103424	18413	32072	17107	68678	68124	37430	116479
Panel C: Varicella by 15 Months											
Pertussis Outbreak	-0.007	-0.004	-0.011	0.001	-0.050**	-0.009	-0.001	-0.007	-0.009	-0.027**	0.002
-10m to 2m	(0.006)	(0.005)	(0.011)	(0.007)	(0.021)	(0.015)	(0.012)	(0.010)	(0.008)	(0.011)	(0.005)
	-0.0259	*-0.0154*	*-0.0377*	*0.0036*	*-0.1736*	*-0.0369*	*-0.0034*	*-0.0247*	*-0.0383*	*-0.0931*	*0.0077*
Pertussis Outbreak	0.015**	0.015*	0.018*	0.023**	0.013	0.001	0.031	0.008	0.017***	0.019	0.012*
3m to 15m	(0.006)	(0.008)	(0.009)	(0.010)	(0.013)	(0.016)	(0.021)	(0.007)	(0.006)	(0.013)	(0.006)
	0.0556	*0.0577*	*0.0616*	*0.0824*	*0.0451*	*0.0041*	*0.1058*	*0.0283*	*0.0723*	*0.0655*	*0.0460*
Y Mean	0.730	0.740	0.708	0.721	0.712	0.756	0.707	0.717	0.765	0.710	0.739
Observations	153909	120842	33067	103424	18413	32072	17107	68678	68124	37430	116479

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table 7: Effects of Pertussis Outbreaks on DTaP Immunization Coverage by 19 Months, 99th Percentile

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: Number of DTaP Vaccinations											
Pertussis Outbreak	0.016*	0.023***	0.002	0.022**	-0.030	0.020	-0.004	0.022*	0.021**	0.025	0.013
-6m to 6m	(0.009)	(0.008)	(0.021)	(0.010)	(0.030)	(0.014)	(0.024)	(0.012)	(0.010)	(0.019)	(0.009)
	0.0045	*0.0063*	*0.0006*	*0.0061*	*-0.0086*	*0.0056*	*-0.0012*	*0.0062*	*0.0057*	*0.0072*	*0.0036*
Pertussis Outbreak	0.017***	0.014***	0.030**	0.009	0.013	0.020*	0.036*	-0.000	0.031***	0.010	0.019**
6m to 18m	(0.006)	(0.005)	(0.014)	(0.009)	(0.021)	(0.011)	(0.020)	(0.010)	(0.009)	(0.018)	(0.009)
	0.0047	*0.0039*	*0.0086*	*0.0025*	*0.0037*	*0.0056*	*0.0104*	*0.0000*	*0.0084*	*0.0029*	*0.0052*
Y Mean	3.581	3.623	3.486	3.607	3.490	3.574	3.474	3.553	3.692	3.494	3.620
Observations	155752	122610	33142	104583	18821	32348	17278	69699	68775	37794	117958
Panel B: Up to Date on DTaP Vaccinations											
Pertussis Outbreak	0.015***	0.013**	0.018	0.010	0.010	0.023**	0.023*	0.013*	0.013**	0.016	0.014***
-6m to 6m	(0.005)	(0.005)	(0.014)	(0.006)	(0.014)	(0.009)	(0.013)	(0.007)	(0.005)	(0.011)	(0.005)
	0.0490	*0.0461*	*0.0496*	*0.0350*	*0.0272*	*0.0730*	*0.0632*	*0.0394*	*0.0558*	*0.0440*	*0.0500*
Pertussis Outbreak	0.005	0.003	0.011	-0.005	0.015	0.012	0.006	0.001	0.007	0.001	0.006
6m to 18m	(0.004)	(0.005)	(0.008)	(0.006)	(0.011)	(0.009)	(0.011)	(0.006)	(0.007)	(0.012)	(0.007)
	0.0163	*0.0106*	*0.0303*	*-0.0175*	*0.0408*	*0.0381*	*0.0165*	*0.0030*	*0.0300*	*0.0027*	*0.0214*
Y Mean	0.694	0.718	0.637	0.714	0.632	0.685	0.636	0.670	0.767	0.636	0.720
Observations	155752	122610	33142	104583	18821	32348	17278	69699	68775	37794	117958

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. In Panel A, the numbers in italicas represent the treatment effects as a percent of the mean. In Panel B, the numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Appendix A. Additional Tables

Table A1: Effects of Pertussis Outbreaks on DTaP Immunization by 75 Days, Additional Coefficients

	95^{th}	99^{th}
Pertussis Outbreak	0.011*	0.010
(12 Months)	(0.005)	(0.007)
Black	-0.028***	-0.028***
	(0.007)	(0.007)
Hispanic	0.020***	0.020***
	(0.005)	(0.005)
Poor	-0.049***	-0.049***
	(0.007)	(0.007)
First Born	0.051***	0.051***
	(0.003)	(0.003)
Male	-0.002	-0.002
	(0.002)	(0.002)
Married	0.041***	0.041***
	(0.006)	(0.006)
HS Grad	0.041***	0.041***
	(0.008)	(0.008)
College	0.104***	0.104***
	(0.009)	(0.009)
Mean	0.788	0.788
Unweighted N	165843	165843

Notes: The key explanatory variable is an indicator for having experienced an outbreak of pertussis in the state of birth during the period starting 10 months prior to birth and ending 2 months after birth. This variable is equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table A2: Effects of Pertussis Outbreaks on DTaP Immunization by 75 Days, Falsification Test

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: 95th Percentile Cutoff											
Pertussis Outbreak	0.001	-0.003	0.006	-0.002	0.014	-0.005	0.011	0.001	-0.005	0.006	-0.002
(3m to 6m)	(0.005)	(0.006)	(0.009)	(0.006)	(0.012)	(0.008)	(0.016)	(0.006)	(0.005)	(0.009)	(0.005)
	0.0047	*-0.0166*	*0.0208*	*-0.0105*	*0.0517*	*-0.0215*	*0.0374*	*0.0044*	*-0.0357*	*0.0218*	*-0.0108*
Panel B: 99th Percentile Cutoff											
Pertussis Outbreak	0.006	0.002	0.011	0.010	-0.015	0.007	0.010	0.011	-0.002	0.009	0.005
(3m to 6m)	(0.008)	(0.008)	(0.010)	(0.007)	(0.026)	(0.015)	(0.016)	(0.013)	(0.006)	(0.017)	(0.006)
	0.0280	*0.0110*	*0.0382*	*0.0526*	*-0.0554*	*0.0300*	*0.0340*	*0.0480*	*-0.0143*	*0.0327*	*0.0269*
Mean	0.786	0.819	0.712	0.810	0.729	0.767	0.706	0.771	0.860	0.725	0.814
Unweighted N	195503	152952	42551	130267	24746	40490	22121	89390	83992	48895	146608

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table A3: Effects of Pertussis Outbreaks on DTaP Immunization by 75 Days, Multiple Percentiles Together

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Pert Cout 50-74 Percentile											
-6m to 0m	-0.001	-0.002	0.002	-0.004	0.015	-0.000	-0.006	0.003	-0.002	-0.002	-0.001
	(0.006)	(0.005)	(0.016)	(0.005)	(0.016)	(0.012)	(0.022)	(0.008)	(0.006)	(0.019)	(0.005)
0m to 2m	0.001	-0.002	0.009	-0.001	-0.007	0.009	0.007	-0.001	0.000	0.001	0.001
	(0.004)	(0.003)	(0.015)	(0.004)	(0.013)	(0.012)	(0.012)	(0.007)	(0.006)	(0.012)	(0.004)
Pert Cout 75-89 Percentile											
-6m to 0m	0.004	0.000	0.011	0.006	0.017	-0.013	-0.010	0.019**	-0.011	0.007	0.002
	(0.007)	(0.005)	(0.019)	(0.005)	(0.018)	(0.017)	(0.026)	(0.008)	(0.007)	(0.017)	(0.006)
0m to 2m	0.008	0.002	0.023	0.004	0.002	0.020	0.010	0.014	-0.002	0.004	0.009*
	(0.006)	(0.005)	(0.017)	(0.004)	(0.015)	(0.015)	(0.012)	(0.009)	(0.006)	(0.013)	(0.005)
Pert Cout 90-94 Percentile											
-6m to 0m	0.004	0.011	-0.011	0.007	0.022	-0.017	-0.005	0.013	-0.003	0.023	-0.007
	(0.009)	(0.007)	(0.020)	(0.010)	(0.018)	(0.019)	(0.024)	(0.013)	(0.008)	(0.016)	(0.008)
0m to 2m	0.009*	0.010	0.010	0.002	-0.020	0.028**	0.019	0.008	0.007	0.012	0.006
	(0.005)	(0.007)	(0.013)	(0.007)	(0.023)	(0.012)	(0.018)	(0.013)	(0.008)	(0.018)	(0.008)
Pert Cout 95-98 Percentile											
-6m to 0m	0.011**	0.005	0.026*	0.004	0.044*	0.012	0.015	0.020*	-0.004	0.022*	0.006
	(0.005)	(0.006)	(0.014)	(0.007)	(0.022)	(0.010)	(0.019)	(0.010)	(0.008)	(0.013)	(0.005)
0m to 2m	0.005	0.005	0.007	0.010*	-0.007	0.002	0.007	0.005	0.007	0.000	0.009
	(0.008)	(0.007)	(0.019)	(0.005)	(0.024)	(0.023)	(0.024)	(0.010)	(0.008)	(0.014)	(0.008)
Pert Cout 99-100 Percentile											
-6m to 0m	0.009	0.002	0.022	0.007	0.011	0.013	0.026	0.013	-0.003	0.016	0.007
	(0.009)	(0.008)	(0.016)	(0.008)	(0.021)	(0.023)	(0.024)	(0.013)	(0.007)	(0.016)	(0.010)
0m to 2m	0.023**	0.000	0.064***	-0.013	0.058**	0.058**	0.076***	0.033**	-0.022**	0.060**	0.005
	(0.011)	(0.013)	(0.019)	(0.017)	(0.023)	(0.023)	(0.027)	(0.014)	(0.011)	(0.027)	(0.014)
Mean	0.788	0.821	0.713	0.812	0.733	0.767	0.707	0.772	0.862	0.725	0.816
Unweighted N	177736	139156	38580	118843	21745	37148	19873	80015	77848	43871	133865

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for the percentile category of the highest 4 week pertussis count in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded falls in the percentile range listed of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table A4: Spillover Effects on Other Immunizations Received at the Same Visit as the First DTaP Dose, 95th Percentile

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: Polio by 75 Days											
Pertussis Outbreak	0.009*	0.000	0.029**	0.001	0.029**	0.021*	0.039*	0.006	-0.001	0.016	0.007
-10m to 2m	(0.005)	(0.004)	(0.011)	(0.005)	(0.014)	(0.011)	(0.020)	(0.005)	(0.005)	(0.011)	(0.005)
	0.0390	*0.0000*	*0.0986*	*0.0047*	*0.1055*	*0.0864*	*0.1313*	*0.0247*	*-0.0058*	*0.0565*	*0.0338*
Y Mean	0.769	0.798	0.706	0.787	0.725	0.757	0.703	0.757	0.829	0.717	0.793
Observations	165843	129802	36041	111214	19847	34782	18477	74165	73201	40644	125199
Panel B: Hib by 75 Days											
Pertussis Outbreak	0.010*	0.003	0.026**	0.004	0.024	0.020*	0.037*	0.006	0.002	0.017*	0.008
-10m to 2m	(0.006)	(0.004)	(0.012)	(0.006)	(0.016)	(0.011)	(0.022)	(0.005)	(0.005)	(0.010)	(0.006)
	0.0444	*0.0158*	*0.0861*	*0.0201*	*0.0851*	*0.0810*	*0.1217*	*0.0249*	*0.0134*	*0.0590*	*0.0408*
Y Mean	0.775	0.810	0.698	0.801	0.718	0.753	0.696	0.759	0.851	0.712	0.804
Observations	165843	129802	36041	111214	19847	34782	18477	74165	73201	40644	125199

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table A5: Spillover Effects on Immunizations Received at Separate Visits From the First DTaP Dose, 99th Percentile, Above the 95th Percentile

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: Measles Containing Vaccine											
Pertussis Outbreak	-0.002	0.004	-0.020*	-0.006	-0.017	0.006	-0.011	-0.000	0.000	-0.007	0.000
-6m to 0m	(0.009)	(0.010)	(0.012)	(0.009)	(0.019)	(0.016)	(0.011)	(0.012)	(0.008)	(0.011)	(0.009)
	-0.0046	*0.0088*	*-0.0514*	*-0.0133*	*-0.0425*	*0.0141*	*-0.0272*	*0.0000*	*0.0000*	*-0.0179*	*0.0000*
Y Mean	0.564	0.543	0.611	0.550	0.600	0.575	0.595	0.577	0.525	0.608	0.544
Observations	181708	142243	39465	121471	22335	37902	20356	81982	79370	44926	136782
Panel B: Measles Containing Vaccine by 15 Months											
Pertussis Outbreak	-0.005	0.003	-0.021***	0.005	-0.025**	-0.021***	-0.018	-0.005	0.002	-0.019***	0.000
-10m to 2m	(0.004)	(0.004)	(0.007)	(0.005)	(0.012)	(0.008)	(0.012)	(0.005)	(0.005)	(0.007)	(0.004)
	-0.0197	*0.0120*	*-0.0798*	*0.0186*	*-0.0896*	*-0.1000*	*-0.0695*	*-0.0189*	*0.0085*	*-0.0699*	*0.0000*
Pertussis Outbreak	0.002	0.003	0.001	0.008	-0.001	-0.008	0.024**	-0.005	0.004	0.011	-0.003
3m to 15m	(0.004)	(0.004)	(0.009)	(0.005)	(0.014)	(0.010)	(0.011)	(0.006)	(0.006)	(0.009)	(0.004)
	0.0079	*0.0120*	*0.0038*	*0.0297*	*-0.0036*	*-0.0381*	*0.0927*	*-0.0189*	*0.0171*	*0.0404*	*-0.0122*
Y Mean	0.746	0.750	0.737	0.731	0.721	0.790	0.741	0.736	0.766	0.728	0.755
Observations	153909	120842	33067	103424	18413	32072	17107	68678	68124	37430	116479
Panel C: Varicella by 15 Months											
Pertussis Outbreak	0.001	0.005	-0.008	0.006	-0.023	-0.006	-0.003	0.002	0.002	-0.008	0.004
-10m to 2m	(0.004)	(0.004)	(0.008)	(0.005)	(0.014)	(0.008)	(0.011)	(0.007)	(0.006)	(0.007)	(0.005)
	0.0037	*0.0192*	*-0.0274*	*0.0215*	*-0.0799*	*-0.0246*	*-0.0102*	*0.0071*	*0.0085*	*-0.0276*	*0.0153*
Pertussis Outbreak	0.005	0.009*	-0.004	0.013	0.014	-0.014	0.010	-0.001	0.011*	0.005	0.004
3m to 15m	(0.005)	(0.005)	(0.009)	(0.008)	(0.015)	(0.012)	(0.011)	(0.007)	(0.006)	(0.009)	(0.006)
	0.0185	*0.0346*	*-0.0137*	*0.0466*	*0.0486*	*-0.0574*	*0.0341*	*-0.0035*	*0.0468*	*0.0172*	*0.0153*
Y Mean	0.730	0.740	0.708	0.721	0.712	0.756	0.707	0.717	0.765	0.710	0.739
Observations	153909	120842	33067	103424	18413	32072	17107	68678	68124	37430	116479

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. The numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.

Table A6: Effects of Pertussis Outbreaks on DTaP Immunization Coverage by 19 Months, 95th Percentile

	Full	Poverty Status		Race and Ethnicity			Mother's Education			Marital Status	
	Sample	Not Poor	Poor	White	Black	Hispanic	LTHS	HS Grad	College	Not Married	Married
Panel A: Number of DTaP Vaccinations											
Pertussis Outbreak	0.008	0.007	0.008	0.010	-0.014	0.012	0.001	0.016	0.001	0.005	0.009
-6m to 6m	(0.008)	(0.008)	(0.016)	(0.010)	(0.015)	(0.015)	(0.023)	(0.010)	(0.010)	(0.019)	(0.008)
	0.0022	*0.0019*	*0.0023*	*0.0028*	*-0.0040*	*0.0034*	*0.0003*	*0.0045*	*0.0003*	*0.0014*	*0.0025*
Pertussis Outbreak	0.002	0.016**	-0.030	0.009	-0.049**	0.001	0.003	-0.007	0.016*	-0.011	0.005
6m to 18m	(0.009)	(0.007)	(0.025)	(0.010)	(0.021)	(0.014)	(0.026)	(0.012)	(0.008)	(0.017)	(0.008)
	0.0006	*0.0044*	*-0.0086*	*0.0025*	*-0.0140*	*0.0003*	*0.0009*	*-0.0020*	*0.0043*	*-0.0031*	*0.0014*
Y Mean	3.581	3.623	3.486	3.607	3.490	3.574	3.474	3.553	3.692	3.494	3.620
Observations	155752	122610	33142	104583	18821	32348	17278	69699	68775	37794	117958
Panel B: Up to Date on DTaP Vaccinations											
Pertussis Outbreak	0.005	0.002	0.012	0.004	-0.003	0.008	0.006	0.010	-0.003	0.003	0.006
-6m to 6m	(0.006)	(0.007)	(0.010)	(0.006)	(0.011)	(0.011)	(0.012)	(0.007)	(0.008)	(0.011)	(0.006)
	0.0163	*0.0071*	*0.0331*	*0.0140*	*-0.0082*	*0.0254*	*0.0165*	*0.0303*	*-0.0129*	*0.0082*	*0.0214*
Pertussis Outbreak	-0.003	0.004	-0.018	-0.003	-0.026**	0.003	-0.012	-0.003	0.002	-0.015	0.001
6m to 18m	(0.005)	(0.004)	(0.012)	(0.007)	(0.011)	(0.008)	(0.012)	(0.007)	(0.004)	(0.010)	(0.005)
	-0.0098	*0.0142*	*-0.0496*	*-0.0105*	*-0.0707*	*0.0095*	*-0.0330*	*-0.0091*	*0.0086*	*-0.0412*	*0.0036*
Y Mean	0.694	0.718	0.637	0.714	0.632	0.685	0.636	0.670	0.767	0.636	0.720
Observations	155752	122610	33142	104583	18821	32348	17278	69699	68775	37794	117958

Notes: All specifications include individual controls, state fixed effects, and month-year of birth fixed effects. n Panel A, the numbers in italicas represent the treatment effects as a percent of the mean. In Panel B, the numbers in italics represent the treatment effects as a fraction of the unvaccinated population. The key explanatory variables are indicators for having experienced an outbreak of pertussis in the state of birth during the relevant reference period. These indicators are equal to one if the family experienced a four week period in which the total number of pertussis cases in the state exceeded the 95th or 99th percentile of all four-week case totals for that state during the sample period. Individual control variables include dummies for child gender, race/ethnicity, and poverty status, and mother's education and marital status. Standard errors (in parentheses) are clustered at the state level. * $p < .10$, ** $p < .05$, and *** $p < .01$. Observations are weighted using NIS sampling weights.