The Effects of Perceived Disease Risk and Access Costs on Infant Immunization

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Abstract: This paper examines the roles of perceived disease risk and healthcare access costs in influencing parental decisions about infant immunization. Using information on 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 diseases. We find that parents of infants 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 larger for children most likely to delay immunization for economic reasons. In addition, we find that parents also increase the likelihood of immunizing their children against other vaccine-preventable diseases. These spillover effects are similar in magnitude to the direct effects, which suggests that access costs play a significant 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, large 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 outbreaks and increasing the number of deaths associated with vaccine-preventable diseases (Feikin, Lezotte, Hamman, Salmon, Chen and Hoffman, 2000; Omer, Enger, Moulton, Halsey, Stokley and Salmon, 2008). Despite health insurance mandates to cover immunizations and campaigns to clarify misconceptions about vaccine safety in recent years, only 71.6 percent of children 19-35 months old had received their full set of recommended vaccines in 2014 (Centers for Disease Control and Prevention, n.d.). Thus, to increase vaccine coverage, more needs to be known about what affects parents' decisions to vaccinate their children, how these behaviors differ across different socioeconomic groups, and when these decisions are made.

In this paper, we examine the roles of perceived disease risk and the costs of accessing vaccines in influencing initial parental decisions about immunization. Our data, which come from the

National Immunization Survey (NIS), allow us to study the determinants of parental choices not only about whether to immunize their children, but *when* to immunize, starting from the time of the first recommended vaccine doses around two months of age. The data also allow us to assess differences across demographic and socioeconomic groups. Our approach is novel for three reasons. First, many studies focus on vaccination during early childhood, particularly at kindergarten—the first immunization "check-point" for most children. However, many children who ultimately end up fully vaccinated by kindergarten, experience substantial delays in their vaccination schedules, causing them to be underimmunized during their first few years of life. Because infants and toddlers have the highest likelihood of catching vaccine-preventable diseases and of experiencing serious complications from them, increasing the rate of on-time vaccination has been an important goal for policymakers (Feemster et al., 2009; Luman et al., 2005). Second, we are the first to study how perceived disease risk affects the on-time *initiation* of immunizations. Since most of the vaccines given to infants are part of a sequence, obtaining the first set of immunizations on time can help establish a routine with a care provider and make it more likely that they will obtain their subsequent vaccines on time as well. Finally, because there are large differences in immunization behaviors across demographic groups, understanding how each group responds to changes in perceived disease risk and access costs will allow policymakers to craft better directed policies.

In order to identify possible policy avenues for increasing vaccine coverage in key underimmunized groups, we focus on heterogeneity between children in low-socioeconomic status families, who are more likely to be underimmunized for economic reasons, and children in high-socioeconomic status families, who are more likely to be underimmunized for reasons related to the perceived health cost of vaccination. With recent outbreaks of pertussis and measles across the United States highlighting the importance of widespread immunization coverage (Centers for Disease Control and Prevention, 2014*a*,*b*), one source of concern is that the increasing number of children whose parents are opting to delay or avoid vaccination due to concerns about vaccine

safety has put other children at risk, including those who too young or sick to be adequately immunized or who are not up-to-date on their vaccines because of cost or limited access to quality healthcare. From a policy standpoint, increasing vaccine coverage among *either* of these under-immunized groups can mitigate this problem. However, because the driving factors influencing the choice to vaccinate are different between the two groups (Omer et al., 2009), the policy tools that will be effective in increasing immunization rates within each of these groups are likely to be different as well.

In the first part of our study, we examine whether information about disease risk influences the likelihood of initiating infant vaccination on time. As rates of vaccine-preventable diseases in the US fell over the 20^{th} century, in some cases to near-zero, the perceived risk of illness among the population fell as well. This has likely contributed to a decline in immunization rates across the board, as even a small expected cost of vaccination outweighs a near-zero perceived individual benefit from vaccination. With the recent resurgence of some vaccine-preventable illnesses, the expected benefit from vaccinating for these illnesses has again increased, particularly for infants, who are the most vulnerable in an outbreak. If the public's awareness of this has lagged the actual change, then information dissemination is a potential avenue by which policy might influence vaccination rates. To explore whether information about disease risk affects vaccination, we link NIS data to weekly state-level pertussis outbreak data from the Center for Disease Control (CDC). Using information on exact date of birth and the timing of each vaccine dose relative to birth date, we estimate the effects of pertussis outbreaks occurring in utero and during the first two months of life on the likelihood of obtaining the first pertussis dose within the recommended time frame, and explore how this effect varies along a number of socioeconomic and demographic dimensions. We separately examine the effects outbreaks occurring in utero or during the first two months of life to better understand *when* decisions about immunization are made.

We find that disease outbreaks occurring in utero and between birth and two months of age increase the probability that the first immunization occurs on-time (within 75 days of birth). This is

consistent with the findings of Oster (2016), who studies the effects of pertussis outbreaks on later vaccination decisions using county-level data on kindergarten vaccination coverage. Splitting our sample along demographic and socioeconomic dimensions provides important additional insight into which segments of the population are responding to outbreaks: we find that the increase in on-time vaccination is larger among minority children, children in low-income households, and children with less-educated mothers—the groups most likely to be underimmunized for economic reasons.

In the second part of our study, we explore the role that access costs play in determining whether infants in economically disadvantaged groups receive vaccines on time. Previous research has found that cost and lack of access to quality medical care are important reasons why poor children have lower rates of up-to-date immunization and lower take-up of preventative care in general (Fu, Cowan, McLaren, Engstrom and Teach, 2009; Guttmann, Manuel, Dick, To, Lam and Stukel, 2006). Disadvantaged mothers of underimmunized children have also cited scheduling challenges, long waiting times, and transportation challenges as barriers to on-time immunization (Lannon, Brack, Stuart, Caplow, McNeill, Bordley and Margolis, 1995). We examine the role of healthcare access costs by looking at spillover effects—the effects of outbreaks of pertussis on vaccination rates for other diseases. Since outbreaks of pertussis are unlikely to increase the actual or perceived risk of catching other diseases, any changes in on-time vaccination for other diseases should be related to changes in the costs associated with obtaining those vaccines once they are already at the doctor's office or clinic.

We find that for black and Hispanic children, children in poor families, and children with less-educated parents, local disease outbreaks both during pregnancy and during the first two months of life cause increases in on-time immunization initiation. Thus, it seems that the spread of information about disease risk to these populations is a potential policy tool for increasing coverage rates. Our results also suggest that the access costs associated with obtaining vaccines (i.e. the costs associated with finding and visiting a vaccine provider) are a significant contributor to under-

immunization. In particular, we show that when a pertussis outbreak induces parents to vaccinate against pertussis, they also choose to immunize against other illnesses at nearly the same rate, even though there has been no change in the expected benefit from those vaccines. Therefore, policies that help disadvantaged families to overcome the costs associated with access to vaccines will be effective in increasing coverage.

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 be up-to-date on their immunizations than the general population (Chu, Barker and Smith, 2004; Feemster et al., 2009; Guttmann et al., 2006; Luman, McCauley, Shefer and Chu, 2003; Smith et al., 2004). These discrepancies 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 be up-to-date with vaccinations (Fu et al., 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). A focus group study highlights a number of additional barriers to immunization among disadvantaged families, including scheduling challenges and transportation costs (Lannon et al., 1995). Although the list of barriers described above includes non-monetary costs, we refer to this group as children who are underimmunized for *economic* reasons, since most of the barriers listed above are more likely to affect families with low income and limited neighborhood resources.

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 deHart, 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, (Gust, Strine, Maurice, Smith, Yusuf, Wilkinson, Battaglia, Wright and Schwartz (2004) estimate that just over 1% of the U.S. birth cohort did not receive at least two core vaccines because of safety concerns) 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). Fur-

thermore, 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), so policy makers need to look for other ways to increase vaccination rates for this group.

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 increasing vaccine coverage. In particular, we stratify the NIS sample by race/ethnicity, family income, and maternal education to see whether the responsiveness of immunization timing to disease outbreaks is different for children who are most likely to undervaccinated for economic reasons than for children who are more likely to be undervaccinated 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 catching 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. Oster's study, which shows an increase in vaccination coverage measured at kindergarten entry following a county pertussis outbreak, provides supporting evidence for this assumption, and shows that individuals may, in fact, substantially underestimate the probability of illness.

We make an important distinction between the expected health costs of vaccinating and other potential vaccine "access costs." For everyone, the health costs of vaccination include injection pain and a small risk of complications from the vaccine. For many marginal families, they may

also include other concerns about perceived vaccine safety. The access costs in our model 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 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 points out, this kind of cost-benefit framework is not inconsistent with the choice not to vaccinate. When the expected benefit of vaccinating (i.e. perceived disease risk) is very low, even small costs can outweigh it. What we expect to see, 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.

Meanwhile, estimating spillover effects can help us to distinguish the role of access costs from the perceived health costs of vaccination. In particular, a pertussis outbreak does not change the expected benefit of vaccination for other illnesses such as measles or polio. It may, however, encourage families to overcome the access costs associated with obtaining vaccines in order to protect their children against pertussis. Once families have already incurred these access costs, the marginal access costs of additional immunizations is lowered substantially. The expected health costs of vaccination, on the other hand, should be unaffected. Therefore, any observed effects of pertussis outbreaks on vaccination for other illnesses will be due only to changes in healthcare access costs.

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 (e.g. Abrevaya and Mulligan 2011; Luca 2016). The paper in this literature that is 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 28 percent) and concave (the per-case effect is larger for the first case of a disease in a county than for subsequent cases). In an analysis of Google data, Oster shows increases in internet searches related to pertussis in the months following a state outbreak, which supports the notion that information about outbreaks is disseminated widely.

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 paper 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 par-

ents 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 barriers to immunization such as perceived safety risks.

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. [1]

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 prior year. Using those weekly reports, we compiled a database that covers the years 1996-2011 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

[1] 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.

disease, we first need to define what an "outbreak" is. Our primary measure of an outbreak is when the weekly pertussis case count is above the 99^{th} percentile of the distribution within a state over time. 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. In some cases, subtracting the previous week's count from the current week results in a negative number of cases or a very large, likely inaccurate, number. For this reason, we always require that both the preliminary *and* revised counts are above the threshold to be considered an outbreak.

Figure 1 gives an example of an outbreak based on this definition. The top left panel displays the number of cases, by week, in Idaho, and the horizontal line gives Idaho's 99^{th} percentile threshold for pertussis cases (34). During 1997, there were 4 weeks above the 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 2012. During that year only Montana experienced an outbreak. Table 1 gives the threshold for each state.

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 between the ages of 19 and 35 months via a household telephone survey and a mail survey of vaccination providers. The data are available from 1995 through 2012[2] and include information on household demographics, as well as the types of vaccinations received and the child's age in days at vaccine receipt. We use the restricted use version of the NIS, that includes each child's 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

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

life. Our main results focus on the on-time receipt of the first dose of the diphtheria, tetanus and acellular pertussis vaccination (DTaP), which is recommended at two months. We also examine whether an increase in on-time receipt of the DTaP vaccination spills over into other two-month immunizations.

Table 2 shows the percentage of children in our sample that were exposed to a pertussis outbreak at different ages. For example, the first row shows that for 6.2% of children, there was at least one week with a pertussis outbreak in their state while they were in utero (nine months prior to birth until birth), and the second row shows that only 1.6% of children were exposed to an outbreak in their state during the first two months of life. Table 3 gives summary statistics for the sample of children who are exposed to an outbreak during their first two months of life compared to those who were not exposed to an outbreak. While the two groups look very similar along most dimensions, we can see that black children are more likely to have been exposed to an outbreak and Hispanic children are less likely. This underscores the importance of controlling for race in pooled regressions as well as the importance of looking at differences in responses to outbreaks between demographic groups. The last three rows give a first look at the differences in means for some of our outcome variables. We can see that, on average, those exposed to a pertussis outbreak are more likely to have received their first DTaP, Hib and Polio vaccinations by the time they are 75 days old.

4. Estimation Strategy

We use a fixed effects model to estimate the effect of disease outbreak shocks 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.

We write the model as:

$$\mathrm{Y}_{isw} \quad = \quad \alpha + \beta \ \textbf{Outbreak}_{sw} + \omega \ X_{isw} + \nu \ U_{sw} + \gamma_s + \gamma_m + \epsilon_{isw} \tag{1}$$

where Y_{isw} is the immunization outcome of interest. For example, one outcome we examine is 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.[3] $\textbf{Outbreak}_{sw}$ is a vector of variables that indicate exposure to a disease outbreak during a series of relevant time periods for a child born in week *w* and in state *s* (a more specific illustrative example is provided below.). U_{sw} is a vector of controls for the average state unemployment rate during the same series of relevant time periods, X_{isw} is a vector of individual child characteristics that includes birth order, gender, race, maternal education, and poverty status, and γ_s and γ_m are full sets of fixed effects for state and month of birth. Standard errors are clustered by state and the regressions are weighted using the NIS survey weights. The β's are the regression coefficients of interest, as they show the effect of an outbreak during each specified time period on the probability of on-time immunization.

As an example, our main set of regressions will investigate the probability of having received the first DTaP vaccination by 75 days of age. The main specification of the model for this regression will be written as follows:

$$\begin{aligned}
\text{First DTaP 75}_{isw} \quad &= \quad \alpha + \beta_1 \text{ Above 99, -9 – 0 months }_{sw} && (2)\\
&+ \quad \beta_2 \text{ Above 99, 0 – 2 months}_{sw} && (3)\\
&+ \quad \omega \ \mathbf{X}_{isw} + \nu \ U_{sw} + \gamma_s + \gamma_w + \epsilon_{isw} && (4)
\end{aligned}$$

where First DTaP 75_{isw} is an indicator equal to one if a child has received her first DTaP im-

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

munization by 75 days old. 'Above 99, -9 – 0 months $_{sw}$' is an indicator equal to one if there was at least one week during the nine months before the child was born when the incidence of pertussis was above the 99^{th} percentile of the state-specific distribution. 'Above 99, 0 – two months $_{sw}$' is equal to one if there was at least one week above the same threshold during the first two months of life.

5. Results

5.1. Effect of Pertussis Outbreaks on On-Time DTaP

The summary statistics presented in the bottom rows of Table 3 suggest that children living in states with a pertussis outbreak during their first two months of life are more likely to have received their first DTaP, Hib, and Polio vaccinations on time. We begin by looking at whether the differences suggested by the raw averages for on-time receipt of DTaP remain once we estimate the effect of outbreaks using the full model described in Section 4. The coefficient in the first row of Table 4 gives the difference in on-time immunization rates for children who live in a state that experienced a pertussis outbreak while they were in utero compared to those who do not. Column (4) gives the results of running the full model, including all demographic control variables and state and month/year fixed effects. Children exposed to an outbreak in utero are 2.4 percentage points more likely to have received their first DTaP vaccination on time. Similarly, the coefficient in the second row shows that those exposed to an outbreak during their first two months are 3.1 percentage points more likely to have been immunized on time. It is also interesting to note that after controlling for poverty status, those children whose mothers have less than a high school degree are 5.8 percentage points *more* likely to be immunized on time, while the opposite is true when looking at unconditional means.[4] Similarly, when controlling for income and education, Hispanic children are just as likely as white children to be immunized on time, although the unconditional

[4]The unconditional means are displayed at the bottom of Table 6 and discussed later in this section.

mean suggests that they are less likely. Looking across columns, we can see that the estimates are very robust to the addition of the control variables and fixed effects. For the remainder of the paper, we will only display the outbreak coefficients of interest, but all regressions include the full set of controls.

Next, we experiment with different outbreak definitions. Column (1) of Table 5 reproduces the coefficients of interest from our preferred specification in the last column of Table 4. In Column (2), the outbreak variables are coded as the *number* of weeks during the time period that the count of pertussis cases was above the 99^{th} percentile. This provides a way of looking at whether the length of an outbreak matters for parental responses. For each additional week above the 99^{th} percentile while in utero, there is an increase of 1.7 percentage points and there is an increase of 2.7 for each week during the first two months. This suggests that while the majority of the outbreak effect comes from having an outbreak of any length, outbreaks that last longer cause a larger increase in on-time vaccinations.

5.2. Results by Subgroup

In Table 6, we split the sample by race/ethnicity, mother's education, and family income in order to examine whether the change in immunization behavior differs across groups. First, we check whether the summary statistics for on-time receipt of the the first DTaP dose match the patterns that have been established in the literature. The row titled "mean" near the bottom of Table 6 provides the weighted mean for the group listed at the top of the column. For example, the first column tells us 78.7% of children receive their first DTaP immunization by the time they are 75 days old. Looking across the columns, we can see that the patterns do match the literature. Black and Hispanic children are less likely to be immunized on time than white children, those living below the poverty line are less likely to be immunized on time than those living above the poverty line and children whose mothers have less than a high school degree are less likely to be immunized on time than those whose mothers have at least a high school degree.

The regression results also show that the response to outbreaks is larger in magnitude and more likely to be statistically significant for the groups that are more likely to be underimmunized. Each column presents the results of estimating Equation 2 separately for the group listed at the top of the column (including all control variables). 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 (i.e. one minus the mean listed at the bottom of the table). While black children are least likely to be immunized on time, an outbreak while in utero results in a statistically significant increase in on-time immunization that is equal to 23.4% of the unvaccinated population. For white children, that number is 10.5% and for Hispanic children it is 9.5%. The pattern is the same for the response to outbreaks during the first two months, but the coefficients are not statistically significant.

Similar patterns emerge when the sample is split by poverty status and mother's education. The response to an outbreak while in utero is statistically significant for all groups, but it is larger in magnitude for those living below the poverty line and for those with less educated mothers. For those living below the poverty line, the increase is equivalent to 13.3% of the unvaccinated children, compared to 8.2% for those living above the poverty line. For children whose mothers have less than a high school education, the increase is equivalent to 16.0% of the unvaccinated population, compared to 9.0% for those with more educated mothers. For policy makers, this heterogeneity in responses is important. It suggests that changes in the perceived risk of remaining unvaccinated have the ability to change immunization behavior, and that this information is most effective for the groups that are most vulnerable and are most likely to be underimmunized for economic reasons.

5.3. Spillovers to Other Two-Month Immunizations

In Table 7, we examine the effect of a pertussis outbreak on immunization rates for other vaccines that are also recommended at two months. Once a parent has decided to vaccinate their

child for pertussis, the cost of adding additional vaccinations at the same time is lower than it is for the first vaccination. They have already located a provider, scheduled an appointment, and paid the time and transportation costs involved in making it to the appointment. If these costs are an important part of the decision to vaccinate, we expect to see similar increases in the on-time receipt of immunizations that can be received at the same time. Indeed, these immunizations are often bundled. More than 90% of those who are vaccinated on time for pertussis also get their first haemophilus influenzae (Hib) and inactivated poliovirus (polio) vaccines on time and 91% of children who receive a DTaP immunization, get their first Hib and polio vaccinations on the same day.

Column (1) of Table 7 displays the effect of a pertussis outbreak on on-time receipt of the first Hib (Panel A) and polio (Panel B) vaccinations for the full sample. In both cases, the magnitude and statistical significance of the coefficients of interest are very similar to the ones for DTaP. This suggests that the spillover effect is very strong, with nearly everyone who is induced to vaccinate against pertussis taking advantage of only having to pay the fixed costs a single time and *also* choosing to add additional vaccinations at the same time. Again, the coefficients are more likely to be statistically significant for the groups that are most likely to be underimmunized. They are larger in absolute magnitude and as a percentage of the portion of children who are un-immunized. These results suggest that access costs play a large role in the decision to immunize on-time. While an increase in the perceived risk of pertussis does not increase the danger of remaining unprotected against polio we see that being induced to obtain a DTaP vaccination also encourages parents to protect their children against other vaccine preventable diseases.

5.4. Falsification Test

Finally, to show the validity of our estimation strategy, we test whether an outbreak just *after* the deadline for on-time vaccinations is correlated with an increase in on-time vaccination. This effect should be zero, as we should not expect *future* outbreaks to influence parents' decisions.

However, if something other than outbreaks is changing over time and across states in a way that is correlated with on-time vaccination rates it could be driving our results and would likely also influence the relationship between outbreaks just after two months and vaccination rates. In particular, we estimate a version of Equation 1 where the coefficient of interest is for a dummy variable that indicates whether there is a pertussis outbreak between three and six months of age.[5] These results are displayed in Table 8. We test this model for outbreaks defined at the 99^{th} percentile and for the 95^{th} percentile. In both cases, the coefficients are very small in magnitude and are not statistically different from zero.

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 undervaccinated, 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 from very low income families, those most likely to be undervaccinated for economic reasons, a pertussis outbreak while the child is in utero increases the likelihood of obtaining their first pertussis vaccination on-time by almost four percentage points. This is more than twice the magnitude of the effect we observe for those who are not living below the poverty line, and even when expressed as a percentage of the population that is not vaccinated on time, it is still more than 1.5 times as large (13% vs 8%). Similarly, responses are largest for black and hispanic children and those whose mothers have less than a high school degree. Since low-

[5]This is not a perfect falsification test, as it's possible that an outbreak that began in the second month could extend into the third month. This would make us more likely to find an effect of "future" outbreaks.

income and minority families are very responsive to changes in their perceived disease risk, this is a population that can effectively be 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. This reveals the significant role that access costs play, particularly for the populations that respond the most. Immunization requires frequent visits to the doctor which are often accompanied by both significant time and monetary 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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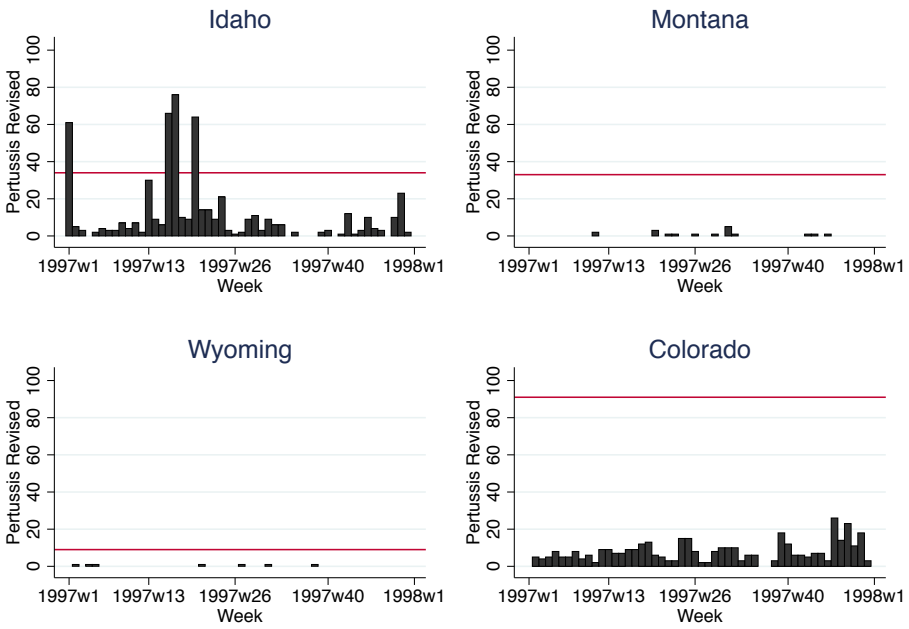
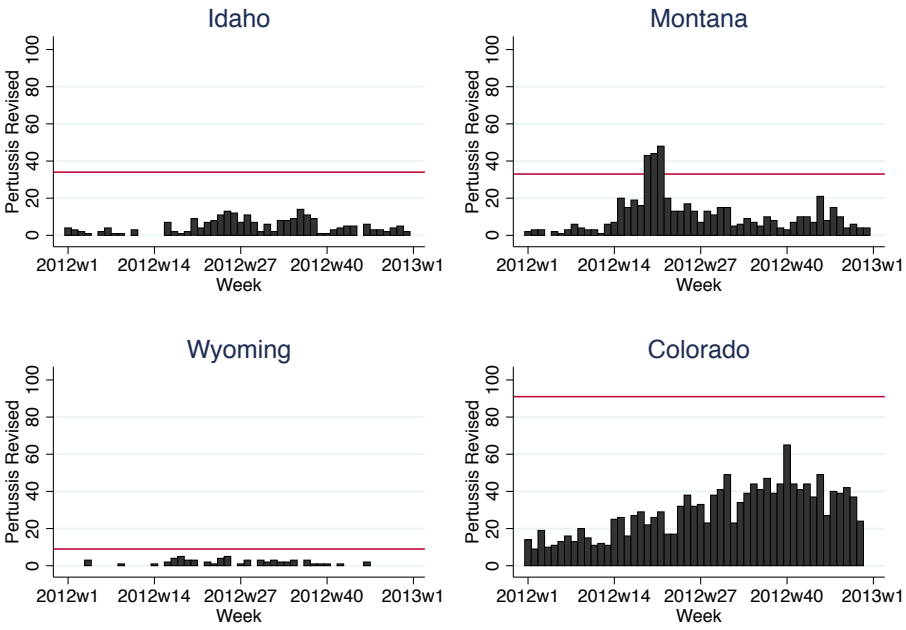
Figure 1: Pertussis Cases in 1997



Notes: This displays the number of pertussis cases per week in a sample of four states. The vertical line gives the 99th percentile for 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 2012



Notes: This displays the number of pertussis cases per week in a sample of four states. The vertical line gives the 99th percentile for 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

AL	15	**MT**	33
AK	18	**NE**	34
AZ	83	**NV**	10
AR	31	**NH**	19
CA	264	**NJ**	37
CO	91	**NM**	32
CT	13	**NY**	64
DE	7	**NC**	38
DC	3	**ND**	42
FL	26	**OH**	70
GA	26	**OK**	21
HI	11	**OR**	41
ID	34	**PA**	57
IL	96	**RI**	12
IN	37	**SC**	22
IA	70	**SD**	13
KS	43	**TN**	15
KY	32	**TX**	196
LA	9	**UT**	74
ME	29	**VT**	22
MD	16	**VA**	31
MA	119	**WA**	157
MI	55	**WV**	9
MN	123	**WI**	210
MS	9	**WY**	9
MO	52		

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

Table 2: Exposure to Outbreaks

Age Range	Mean	sd
In Utero	0.062	0.014
0-2m	0.016	0.004

Notes: This table gives the percentage of children in the National Immunization Survey (NIS) who were exposed to a pertussis outbreak during relevant age ranges. NIS survey weights are used.

Table 3: Summary Statistics by Pertussis Outbreak Experience During First Two Months

	Outbreak		No Outbreak	
	mean	sd	mean	sd
Birth Year	2005.614	0.256	2004.523	0.129
Black	0.150	0.018	0.142	0.021
Hispanic	0.281	0.045	0.326	0.065
$<$100% PL	0.317	0.019	0.316	0.019
High School	0.808	0.015	0.792	0.022
First Born	0.433	0.006	0.423	0.007
Male	0.513	0.003	0.511	0.001
1st DTaP by 75 Days	0.794	0.004	0.780	0.005
1st HIB by 75 Days	0.781	0.004	0.767	0.005
1st Polio by 75 Days	0.776	0.005	0.761	0.006

Notes: This table gives summary statistics for the sample of children who were exposed to a pertussis outbreak in the first column and for children who were not exposed to an outbreak in the second column. Data come from the National Immunization Survey (NIS), and survey weights are used.

Table 4: On Time Receipt of First DTaP Immunization

	(1)	(2)	(3)	(4)
OB: In Utero	0.0245***	0.0258***	0.0257***	0.0238**
	(0.0063)	(0.0070)	(0.0069)	(0.0094)
OB: b - 2m	0.0336***	0.0370***	0.0384**	0.0309**
	(0.0122)	(0.0135)	(0.0149)	(0.0131)
UR: In Utero		0.0024	0.0020	0.0006
		(0.0027)	(0.0030)	(0.0058)
UR: b - 2m		-0.0044	-0.0020	-0.0014
		(0.0030)	(0.0035)	(0.0057)
Black			-0.0433***	-0.0467***
			(0.0077)	(0.0081)
Hispanic			0.0078	0.0099
			(0.0078)	(0.0072)
$<$100% PL			-0.0809***	-0.0787***
			(0.0078)	(0.0077)
$<$ HS			0.0578***	0.0583***
			(0.0087)	(0.0086)
First Born			0.0455***	0.0459***
			(0.0028)	(0.0028)
Male			-0.0009	-0.0006
			(0.0033)	(0.0031)
State FE	No	No	No	Yes
Month/Year FE	No	No	No	Yes
Mean	0.785	0.785	0.787	0.787
N – Unweighted	150,198	150,198	141,825	141,825
N – Weighted	49,941,090	49,941,090	46,049,777	46,049,777

Notes: This table gives the results of estimating the following model: First DTaP $75_{isw} = \alpha + \beta$ **Outbreak**$_{sw} + \omega\ X_{isw} + \nu\ U_{sw} + \gamma_s + \gamma_m + \epsilon_{isw}$ using the full NIS sample. Column (4) gives the results from estimating the full model, while the first three columns show the how the βs change as additional control variables are added. Mean values of the outcome variable are listed at the bottom of the column. Standard errors are shown in parentheses and are clustered by state. * p<0.05, ** p<0.01, *** p<0.001

Table 5: Different Outbreak Definitions
On Time Receipt of First DTaP Immunization

	(1) State 0/1	(2) State #
OB: In Utero	0.0238**	0.0173**
	(0.0094)	(0.0082)
OB: b - 2m	0.0309**	0.0266**
	(0.0131)	(0.0113)
Mean	0.787	
N – Unweighted	141,825	
N – Weighted	46,049,777	

Notes: This table gives the βs estimated using the following model: First DTaP $75_{isw} = \alpha + \beta$ **Outbreak**$_{sw} + \omega\ X_{isw} + \nu\ U_{sw} + \gamma_s + \gamma_m + \epsilon_{isw}$. Outbreak variables in Column (1) are indicator variables equal to one if there was at least one week above the state's threshold, while in Column (2), they give the # of weeks above the threshold. The mean of the outcome variable is listed at the bottom of the table. Standard errors are shown in parentheses and are clustered by state. * p<0.05, ** p<0.01, *** p<0.001

Table 6: Subgroup Analysis: On Time Receipt of First DTaP Immunization

	(1) Full	(2) White	(3) Black	(4) Hispanic	(5) <100% PL	(6) >100% PL	(7) < HS	(8) >= HS
OB: In Utero	0.0238**	0.0199	0.0622***	0.0220*	0.0379*	0.0146*	0.0465*	0.0174**
	(0.0094)	(0.0151)	(0.0210)	(0.0126)	(0.0193)	(0.0083)	(0.0247)	(0.0080)
	0.1117	*0.1053*	*0.2338*	*0.0952*	*0.1325*	*0.0816*	*0.1598*	*0.0897*
OB: b - 2m	0.0309**	0.0065	0.0757	0.0436	0.0224	0.0331	0.0766*	0.0168
	(0.0131)	(0.0099)	(0.0454)	(0.0281)	(0.0223)	(0.0200)	(0.0450)	(0.0101)
	0.1451	*0.0344*	*0.2846*	*0.1887*	*0.0783*	*0.1849*	*0.2632*	*0.0866*
Mean	0.787	0.811	0.734	0.769	0.714	0.821	0.709	0.806
N – Unweighted	141,825	93,409	17,508	30,908	31,459	110,366	16,236	125,589
N – Weighted	46,049,777	25,669,693	6,649,467	13,730,616	14,575,035	31,474,742	8,775,897	37,273,880

Notes: This table gives the βs estimated using the following model: First DTaP $75_{isw} = \alpha + \beta$ **Outbreak**$_{sw} + \omega\ X_{isw} + \nu\ U_{sw} + \gamma_s + \gamma_m + \epsilon_{isw}$ for the group listed at the top of the column. The mean of the outcome variable for the relevant group is listed at the bottom of each column. Standard errors are shown in parentheses and are clustered by state. 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. * p<0.05, ** p<0.01, *** p<0.001

Table 7: Spillovers: On Time Receipt of Other 2-Month Immunizations

	(1) Full	(2) White	(3) Black	(4) Hispanic	(5) <100% PL	(6) >100% PL	(7) < HS	(8) >= HS
Panel A: Polio								
OB: In Utero	0.0201**	0.0167	0.0491**	0.0247*	0.0358*	0.0106*	0.0484*	0.0129*
	(0.0077)	(0.0111)	(0.0223)	(0.0142)	(0.0181)	(0.0060)	(0.0251)	(0.0068)
	0.0866	*0.0777*	*0.1792*	*0.1021*	*0.1222*	*0.0522*	*0.1635*	*0.0594*
OB: b - 2m	0.0320**	0.0052	0.0899	0.0487*	0.0396*	0.0260	0.0865**	0.0153
	(0.0121)	(0.0108)	(0.0560)	(0.0272)	(0.0228)	(0.0197)	(0.0398)	(0.0118)
	0.1379	*0.0242*	*0.3281*	*0.2012*	*0.1352*	*0.1281*	*0.2922*	*0.0705*
Mean	0.768	0.785	0.726	0.758	0.707	0.797	0.704	0.783
N – Unweighted	141,825	93,409	17,508	30,908	31,459	110,366	16,236	125,589
N – Weighted	46,049,777	25,669,693	6,649,467	13,730,616	14,575,035	31,474,742	8,775,897	37,273,880
Panel B: Hib								
OB: In Utero	0.0164**	0.0141	0.0490***	0.0150	0.0199	0.0127	0.0313	0.0134
	(0.0066)	(0.0134)	(0.0167)	(0.0155)	(0.0126)	(0.0086)	(0.0229)	(0.0084)
	0.0726	*0.0705*	*0.1738*	*0.0610*	*0.0661*	*0.0665*	*0.1030*	*0.0647*
OB: b - 2m	0.0287**	0.0029	0.1045**	0.0280	0.0287	0.0262	0.0723*	0.0143
	(0.0134)	(0.0113)	(0.0440)	(0.0316)	(0.0244)	(0.0188)	(0.0419)	(0.0116)
	0.1270	*0.0145*	*0.3706*	*0.1138*	*0.0953*	*0.1372*	*0.2378*	*0.0691*
Mean	0.774	0.800	0.718	0.754	0.699	0.809	0.696	0.793
N – Unweighted	141,825	93,409	17,508	30,908	31,459	110,366	16,236	125,589
N – Weighted	46,049,777	25,669,693	6,649,467	13,730,616	14,575,035	31,474,742	8,775,897	37,273,880

Notes: This table gives the βs estimated using the following model: $\text{Outcome}_{isw} = \alpha + \beta$ **Outbreak**$_{sw} + \omega\ X_{isw} + \nu\ U_{sw} + \gamma_s + \gamma_m + \epsilon_{isw}$ for the group listed at the top of the column. The outcome variable is is an indicator variable equal to 1 if the child received their first Polio (Panel A) or Hib (Panel B) vaccination by 75 days. The mean of the outcome variable for the relevant group is listed at the bottom of each panel's column. Standard errors are shown in parentheses and are clustered by state. 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. * p<0.05, ** p<0.01, *** p<0.001

Table 8: Falsification Test: Outbreak *After* two months on DTaP75

	(1) 99th	(2) 95th
OB: 3m- 6m	0.0004	-0.0016
	(0.0111)	(0.0057)
Mean	0.786	0.786
N – Unweighted	178,439	178,439
N – Weighted	54,872,515	54,872,515

Notes: This table gives the βs estimated using the following model: First DTaP $75_{isw} = \alpha + \beta$ **Outbreak**$_{sw} + \omega\ X_{isw} + \nu\ U_{sw} + \gamma_s + \gamma_m + \epsilon_{isw}$. Column (1) gives the effect of an outbreak above the 99th percentile, while Column (2), gives the effect of an outbreak above the 95th percentile. The mean of the outcome variable is listed at the bottom of the table. Standard errors are shown in parentheses and are clustered by state. * p<0.05, ** p<0.01, *** p<0.001