Intergenerational Benefits of Childhood Health Intervention: Evidence from Measles Vaccination*

Hamid Noghanibehambari†

Abstract

Previous literature suggested that promoting childhood health could have intergenerational benefits. While several studies have pointed to the life-cycle benefits of mass vaccinations and disease eliminations, fewer studies have explored their long-run intergenerational aspects. This paper joins the ongoing literature by exploring the intergenerational health benefits of mothers' childhood exposure to the measles vaccination for their infants' birth outcomes. Our identification strategy takes advantage of cross-cohort exposure to the introduction of the measles vaccine in 1963 and cross-state variations in pre-vaccine measles rates. Using the universe of birth records in the US over the years 1970-2004, we show that mothers who were exposed to the measles vaccine reveal improved birth outcomes. For mothers in states with an average pre-vaccine measles rate, full exposure to the vaccine during childhood is associated with roughly 5.4 and 5.7 percent reduction in the incidence of low-birth-weight and preterm-birth newborns. A series of event-study analyses suggest that these findings are not driven by preexisting trends in outcomes. Further analyses suggest that improvements in educational outcomes, increases in prenatal care utilization, reductions in smoking, and increases in several measures of socioeconomic status are potential mechanism channels.

Keywords: Intergenerational Effects, Birth Outcomes, Infant Health, Vaccination, Measles, Childhood Health, Public Health, Prenatal Health Utilization

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† Center for Demography of Health and Aging, University of Wisconsin-Madison, 1180 Observatory Drive, Madison, WI 53706
Email: noghanibeham@wisc.edu, Phone: +1-806-620-1812, ORCID ID: https://orcid.org/0000-0001-7868-2900

1. Introduction

The 20th century witnessed remarkable advancements in the field of vaccination, which have had a significant impact on public health. Vaccines became widely available for diseases such as smallpox, polio, measles, mumps, rubella, and others. Vaccines have played a crucial role in preventing illness, hospitalization, and death, as well as reducing healthcare costs and the spread of infectious diseases. While these benefits of vaccination are more immediate and easy to detect, there are spillovers and externalities in vaccination. The externalities lie in the fact that vaccination is not just a personal decision but also has broader implications for the entire population's health, non-health outcomes, longer-run outcomes, and spillover influences across generations.

An important achievement of such mass vaccination campaigns -with documented short-run and long-run benefits- is the case of the Measles vaccine introduction in the United States. Measles is a highly contagious disease that could directly deteriorate childhood health capital. It could also indirectly compromise children's immune system and make them more susceptible to other pathogens through an *immunosuppression* process that induces "*immune amnesia*" in immune memory cells (Mina et al. 2015). Measles disables immune memory making individuals more susceptible to other diseases for several years (Mina et al. 2015; Sato and Haraguchi 2021). Prior to the vaccine, roughly 90 percent of children would have contracted the disease by age 12 (Mclean and Anderson 1988). In 1963, the US Food and Drug Administration approved the license of the measles vaccine. The introduction of the measles vaccine was coupled with the Vaccination Assistance Act (VAA) of 1962, which initiated federal interventions in promoting vaccination campaigns by providing funds and grants to state and local health departments. The measles vaccine and joint federal-local efforts resulted in a relatively high take-up rate and immunity among children. By 1967-1970, the annual measles case rates dropped by about 80 percent relative to the pre-vaccine case rates (Conis 2019). Since cohorts who do not contract measles due to vaccination are also less likely to contract other pathogens, one would expect them to accumulate higher health and human capital development. The health and human capital improvements can then be translated into better lifecycle outcomes with potential intergenerational effects.

This paper directly examines the externality of measles vaccination for the health of the next generation. We investigate whether higher exposure to the measles vaccine during childhood impacts the next generation's birth outcomes. The exposure variation comes from the 1963 introduction of measles vaccination coupled with pre-vaccine measles rates and the fact that different cohorts had differential exposure to the vaccine. We show that infants of mothers with higher exposure to measles vaccination during their (mothers') childhood reveal modest but significant increases in birth weight and reductions in low birth weight. We provide event-study results to argue against the concerns over preexisting trends in birth outcomes. Moreover, the results suggest larger impacts among low-educated mothers. Finally, we find suggestive evidence of improvements in educational outcomes, increases in prenatal care, earlier utilization of prenatal care, reductions in smoking, increases in income, and improvements in socioeconomic measures as mechanism channels.

The existing literature evaluates the link between childhood conditions and long-run intergenerational outcomes in various contexts and aspects (Smith 2009; Almond, Currie, and Duque 2018). For instance, several studies show that childhood economic, health, and emotional circumstances affect later-life maternal birth outcomes and can be detected in the health of the next generation of infants (Giallo et al. 2020; East et al. 2023; Noghanibehambari 2022). These studies provide a theoretical basis for the potential long-term and intergenerational benefits of measles vaccination. However, although several studies have pointed to the long-term benefits of measles vaccination for an array of health, economic, and educational outcomes, no study has explored its intergenerational benefits (Driessen et al. 2015; Atwood 2022). Specifically, no study has examined its impacts on later-life maternal birth outcomes. This study aimed to fill this gap in the literature.

Therefore, the contribution of this study to the literature is twofold. First, this is the first study to assess the impacts of childhood vaccination on later-life (maternal) birth outcomes. This aspect of the study contributes to the ongoing research on long-term later-life benefits of childhood health and well-being conditions (Almond, Currie, and Duque 2018; Hayward and Gorman 2004). Second, this study also adds to the literature on the benefits of vaccination. Specifically, we add to the limited empirical studies examining the intergenerational externalities of childhood immunity to diseases. We provide evidence of its benefits for the next generation's birth outcomes. The intergenerational effects of childhood measles vaccination are an understudied field with important potential policy implications.

The rest of the paper is organized as follows. Section 2 reviews the literature. Section 3 introduces data sources and discusses the sample selection strategy. Section 4 discusses the empirical method and identification strategy assumptions. Section 5 reviews the results. Finally, we depart some concluding remarks in section 7.

2. Pathways between Healthier Childhood and Next Generations' Health at Birth

Childhood measles vaccination could affect the next generations' birth outcomes through several channels. In this section, we review the relevant literature.

Measles may cause immune amnesia and expose individuals to other diseases for several years.[3] Therefore, one pathway of the impact of measles vaccination is through reductions in disease burden during childhood. One strand of the literature explores the influence of childhood exposure and contraction of infectious diseases and general disease burden on later-life outcomes (Case and Paxson 2010; Case, Fertig, and Paxson 2005) .[4] For instance, Bleakley (2007) showed that cohorts exposed to Hookworm eradication during childhood reveal higher literacy, school attendance, and income. Case & Paxson (2009) documented that exposure to a disease environment in early-life was associated with lower cognitive scores during old age. Peracchi & Arcaleni (2011) used data from Italy and showed that early-life disease burden negatively affects young men's height and BMI. Bloom et al. (2011) employed data from the Philippines and showed that early childhood vaccination did not affect later-life height but significantly impacted cognitive test scores.

Another pathway through which measles vaccination may affect maternal birth outcomes is through improvement in later-life health, education, and labor market outcomes (Mrozek-Budzyn et al. 2013; Anekwe et al. 2015; Nandi et al. 2019). For instance, Driessen et al. (2015) exploited the roll-out of measles vaccination across districts of Bangladesh and found that age-appropriate vaccination was associated with a higher probability of school attendance among boys. Nandi, Shet, et al. (2019) showed that measles vaccination in early-life was associated with higher BMI-for-age, height-for-age, and Picture Vocabulary Test scores in ages 7-12. Atwood (2022) exploited the introduction of the measles vaccine in 1964 in the US to examine its later-life labor

[3] This is in contrast to other infectious diseases such as polio, for which vaccination campaign started in the 1950s.
[4] Other studies have documented an association between health and human capital during childhood (not neceesarily related to disease burden) and later-life outcomes, including education, earnings, employment, diseases, disability, self-reported well-being, hospitalization, and old-age health (Almond and Currie 2011; Almond, Currie, and Duque 2018; Smith 2009).

market impacts. She found that cohorts in states with higher exposure to pre-vaccine measles rates revealed higher earnings as adults and were more likely to be employed. Chuard et al. (2022) showed that cohorts who were exposed to measles vaccination in the US revealed improvements in education, measures of socioeconomic status, and reductions in disability. Summan et al. (2022) investigated the effects of the Universal Immunization Program (UIP) of India, a government-run program aimed at providing free and mandatory vaccination to all children and pregnant women against preventable diseases. They found that cohorts with a higher exposure to the program during early-life reveal higher wages and household consumption expenditure during adulthood. Nandi et al. (2020) showed that vaccination under the UIP program in early life is associated with about 0.2 more years of schooling later in life.

Therefore, the literature suggested that disease/vaccine exposure in early life may influence anthropometric outcomes, cognitive ability, test scores, educational outcomes, and health status during adulthood. The vaccine-induced health improvements and these later-life impacts can potentially contribute to the next generation's health capital at birth (Currie & Moretti, 2003; Gage et al., 2013; Lindo, 2011; Mocan et al., 2015). For instance, Noghanibehambari et al. (2022) examined the effects of maternal education on birth outcomes and found that an additional year of maternal schooling was associated with 34 grams higher birth weight. Lindo (2011) showed that parental job loss is associated with significant reductions in birth weight. Mocan et al. (2015) documented relatively small but significant impact of maternal earnings on birth weight of their infants.

3. Data and Sample Selection

The primary data source is public-use Natality birth record data extracted from NCHS (2020). The data covers the years 1970-2004. We restrict the sample to mothers born between

1930-1980. Since birth outcomes of teenage mothers and older mothers could be largely driven by age-related factors, we restrict the sample to mothers between the ages of 19-40 (Letamo and Majelantle 2001; Ben-David et al. 2016).[5] Moreover, we limit the sample to singleton births since birth outcomes of multiple births are also primarily driven by factors unrelated to maternal exposures (Vohr et al. 2009). We also exclude observations with missing values on birth weight and gestational age.

We use the 12-year-average cross-state measles rate for the years prior to the vaccine, i.e., the period of 1952-1963, extracted from Atwood (2022).[6] We merge this data with birth record data based on the mother's state-of-birth.[7] To control for other mothers' state-of-birth-level time-varying features, we use average state-level characteristics using decennial census data extracted from Ruggles et al. (2020) and interpolate them for inter-decennial years.[8]

The final sample includes 73,932,418 observations from 49 US states.[9] The outcomes that we examine are described below. Birth Weight is the infant's weight at birth and is measured in grams. Low birth weight is a binary outcome that equals one if the birth weight is less than 2,500 grams. Very Low birth weight is a binary outcome that turns on if the birth weight is less than 1,500 grams. Fetal growth is gain in weight per week of gestation, i.e., birth weight divided by gestational weeks. Full-Term Birth Weight is the birth weight of infants at maturity, i.e., those

[5] In Appendix L, we show the robustness of the results to relaxing this age restriction.
[6] In Appendix G, we show the robustness of the results to using the past 3-years, 6-years, and 9-years average of measles rate as the benchmark intensity variation.
[7] Between the years 1970-1979, roughly 3 million records do not contain birth-state. In Appendix E, we use mother's state-of-residence as a proxy for birth-state for these missing information records. We then replicate the main results and find effects that are almost identical to the main results of the paper.
[8] In Appendix D, we explore the robustness of the results to including covariates from the nearest censuses rather than using the linear cross-census interpolation of control variables. We observe quite comparable results to the main findings of the paper.
[9] The measles data for Kansas and Alaska is not available.

with a gestational age of between 37-42 weeks. Gestational-Age-Adjusted Birth Weight is the predicted value of regressing birth weight on gestational age.

Table 1 Here

Table 1 provides summary statistics of the final sample. The first panel reports infants' characteristics, and the second-panel reports mothers' sociodemographic features. The average birth weight in the sample is 3,364 grams. On average, 6 percent of births are categorized as low birth weight. About 49 percent of infants are female. Roughly 30 percent of births in the sample occur among first-time mothers. The average 12-year measles rate from 1952 to 1963 is 924 cases per 100,000, with a standard deviation of 538. The top panel of Figure 1 shows the geographic distribution of the 12-year pre-vaccine measles rate by mother's state-of-birth. The bottom panel shows infants' birth weight distribution by their mother's state-of-birth.

Figure 1 Here

4. Empirical Method

Our econometric method is built on cross-cohort variation in the share of exposure to the vaccine's introduction and cross-state variation in pre-vaccine concentration of measles rate.[10] Specifically, we implement the following difference-in-difference regressions:

$$y_{ibcst} = \alpha_0 + \alpha_1 ShareExp_c \times Measles_b^* + \alpha_2 X_i + \alpha_3 Z_{bc} + \theta_{st} + \xi_c + \zeta_b \times T_c + \varepsilon_{bcst} \qquad (1)$$

[10] This combination of cohort-level exposure and cross-region of variation by pre-event case rate has been used in many studies with a similar setting (Atwood, 2022; Bleakley, 2007; Cutler et al., 2010; Finkelstein, 2007; Lucas, 2010).

Where y is the birth outcome to mother i who was born in state b and year c, who is observed in state s and year t.[11] The variable $ShareExp$ is the share of childhood up to age 12 that the mother could have been exposed to the introduction of the vaccine.[12] It varies between zero (unexposed cohorts) and one (fully exposed cohorts). The variable $Measles^*$ represents the state-of-birth-specific 12-year average measles rate prior to the vaccine.[13] To ease the interpretation, we divide it by its mean across all states. Therefore, the parameter α_1 measures the effect of full exposure to the vaccine introduction (versus no exposure) and a reduction in state-specific measles rate from the average of pre-vaccine rates to zero on next generations' birth outcomes. Note that the main effects of these variables are absorbed by fixed effects. In X, we include dummies for race, ethnicity, age, education, and prenatal visits. In Z, we include the mother's birth-state by birth-year covariates, including average socioeconomic index, female labor force participation rate, literacy rate, the share of married individuals, and the average number of children. State-of-birth and year-of-birth fixed effects are represented by ζ and ξ, respectively. We also include a birth-state-specific linear trend to account for the secular and linear evolution of time-varying characteristics of mothers' birth-states. The parameter θ represents the current state-of-residence by current year fixed effects. The interaction of these two dimensions of fixed effects absorbs all time-varying unobserved characteristics of mothers' state-of-residence. Therefore, the model fully controls for all state-level policy changes or all state-specific economic and sociodemographic shocks that vary year by year. We cluster the standard errors at the mother's birth-state level to

[11] We refer to the current state, where the mother gives birth, state-of-residence and we refer to the year of giving birth as simply the year. We should also note that state-of-birth and year-of-birth refer to state and year in which the mother was born.

[12] In Appendix F, we explore the effects across alternative cut-off age as well as using a measure of age-at-exposure to flexibly account for differences in the intensity of the effects across various ages. We find much larger impacts among earlier childhood years, specifically ages 0-6.

[13] One potentially useful alternative would be to use state-level per capita vaccine funding or the number of vaccine-doses that were administered as the measure of intensity of treatment exposure. Nonetheless, none of these measures are available.

account for serial correlation and birth-year level to account for spatial correlation in the error terms. In Appendix A, we show that the results are quite robust to alternative clustering levels.

5. Results

5.1. Concerns over Preexisting trends: Event-Study Analysis

The 1950s-1970s are decades of rapid drug/vaccine innovations and improvements in public health. A concern in interpreting our results is that there are preexisting trends of public health promotion in states with higher/lower pre-measles-vaccine measles rates and that the effects are picking up on the unobserved trends. To address this concern, we implement an event-study analysis in which the event is the introduction of the vaccine in 1963, and the event time is years relative to the year a mother turns 12[14]. We implement specifications similar to equation 1 and replace $ShareExp$ with event dummies. Specifically, we implement the following regressions:

$$y_{ibcst} = \alpha_0 + Measles_b^* \times \{\sum_{i=\underline{T}}^{-2} \beta_i I(Year\ Turn\ 12 - 1963 = i) + \sum_{j=0}^{\overline{T}} \gamma_j I(Year\ Turn\ 12 - 1963 = j)\} + \alpha_2 X_i + \alpha_3 Z_{bc} + \theta_{st} + \xi_c + \zeta_b \times T_c + \varepsilon_{bcstt} \quad (2)$$

Where $I(.)$ is an indicator function, and all other parameters are as in equation 1. The set of parameters β_i and γ_j are the event-time coefficients of interest.

In Figure 2, we depict the event-study results for birth weight and low birth weight in the top and bottom panels, respectively. The negative event-time coefficients are virtually zero in magnitude and statistically insignificant. The effects start to rise (in magnitude) for cohorts who were partially exposed to the vaccine and become stable for fully exposed cohorts (i.e., those born

[14] Studies show that roughly 90 percent of children contract measles by age 12 (Mclean and Anderson 1988).

post-vaccine). In Figure 3, we replicate the event-study analysis for gestational age and preterm birth. We observe virtually similar patterns of effects. The negative event-time coefficients (representing unexposed cohorts) do not reveal an economically and statistically significant association. This set of coefficients rules out the concerns over pre-trend for various measures of physical growth-related infants' outcomes. Positive event-time coefficients start to rise in magnitude and become significant for partially exposed cohorts. For fully exposed cohorts, the effects become stable in magnitude and remain statistically significant.

Figure 2 Here

Figure 3 Here

Before moving to the main results, we also discuss another source of endogeneity. An issue that needs to be addressed when interpreting the main findings is the selective selection of mothers into the maternity ward, in other words, endogenous fertility. For example, it is possible that black mothers exhibit higher fertility rates during adulthood and are more likely to enter the maternity ward (i.e., our sample) due to improvements in health during their childhood because of vaccination. Since black mothers generally experience poorer birth outcomes for unobservable reasons, the coefficients might underestimate the actual effects since the sample includes a higher proportion of black mothers. To investigate this source of endogeneity, we conduct a regression analysis of several observable maternal characteristics on our exposure measures while controlling for fixed effects, trends, and birth-state covariates. The results of this analysis can be found in Appendix K. The results do not point to a significant and consistent pattern of endogenous fertility effects.

5.2. Main Results

The main results of the paper are reported in Table 2. The findings suggest significant improvements in birth outcomes for mothers with higher childhood exposure to the measles vaccine. For instance, among fully exposed mothers relative to unexposed mothers, a reduction in measles rate from the average of pre-vaccine rates to zero (roughly equivalent to the reduction in measles after the vaccine was available) was associated with roughly 5.8 grams higher birth weight (column 1), 29 basis-points lower probability of low birth weight (column 2), and 6.9 basis-points lower likelihood of very low birth weight (column 3). In addition, the results suggest that the benefits are considerably larger for infants at the lower tails of birth weight distribution as the percent changes from the mean of the outcome (reported in the last row) imply. For instance, the implied percent change for low birth weight and very low birth weight are 5 and 9 percent, respectively, versus 0.36 percent for mean birth weight. We further probe this heterogeneity by evaluating the effects across various birth weight thresholds. Specifically, we define a series of binary variables that indicate whether an infant's birth weight is above a specific threshold. We then use these indicators as the outcome in our fully parametrized regressions. We depict the results in the top panel of Figure 4. In this graph, the outcomes are on the vertical axis, and the horizontal axis refers to the coefficient of interest (α_1 in equation 1). Since the interpretation of effects require a baseline value and these are the effects across various outcomes, we divide point estimates and confidence intervals by the mean of their respective outcome and illustrate the results in the bottom panel of Figure 4. The implied effects (relative to the mean of the outcomes) suggest larger effects for lower thresholds of low-birth-weight definition. There is a monotonous trend in the magnitude of implied percentage changes with respect to the thresholds, i.e., at lower thresholds, we observe larger effects. This fact suggests that the effects are larger for infants at the lower tails of birth weight distribution.

Figure 4 Here

Table 2 Here

In column 3, we explore the effects on fetal growth, which measures infants' intrauterine weekly weight gain. The results suggest an increase in fetal growth of about 0.15 grams per week of gestation, although the coefficient is statistically insignificant. This effect is about a 0.17 percent rise from the mean of the outcome. Comparing the implied percentage change with that of birth weight in column 1 suggests that part of increases in birth weight can be explained by variations in the gestational period. We also observe an increase of 0.13 weeks of gestation, roughly a 0.4 percent change from the mean (column 4). Similar to the birth weight-related outcomes, we observe larger effects on preterm birth, with roughly 66 basis-points decrease, equivalent to a 5.7 percent reduction in the incidence of premature birth with respect to the mean of the outcome. This fact suggests that the impacts are primarily concentrated among infants at the lower tail of gestational age distribution.

5.3. Robustness Checks

In this section, we explore the sensitivity of the main results to alternative specification checks. To control for cross-cohort convergence in birth outcomes across census regions, we include the mother's region-of-birth-by-birth-year fixed effects in our fully parametrized regressions and replicate the results. The estimated effects are reported in panel A of Table 3. The effects reveal a slight drop in magnitude but remain significant in all cases. Moreover, the marginal effect of fetal growth is precisely estimated in this specification.

Table 3 Here

One concern in interpreting the main results is the endogeneity due to time-variant health improvements across states that could be correlated with our vaccine exposure measure. To address this potential omitted variable bias, we include in our regressions a series of (mothers') state-year-of-birth measures of infant mortality rate, all-age mortality rate, and general fertility rate. These variables are extracted from Bailey et al. (2016). The results, reported in panel B of Table 3, suggest similar effects compared with the main results.

Several studies suggest that health endowment during childhood generates a selective migration pattern (Halliday and Kimmitt 2008; Norman, Boyle, and Rees 2005). Moreover, the choice of residential location also influences health outcomes through many channels, such as local social programs, economic conditions, safety, access to healthcare, and air quality. To control for the potential confounding influence of migration, we interact state-of-birth by state-of-residence fixed effects. Therefore, the model compares the outcomes across mothers born and gave birth in the same set of birth-state and residence-state. The results are reported in panel C of Table 3. We observe very similar effects to the main results. To further explore this issue, we replicate the main results of Table 2 for mothers who give birth in their own birth-state (i.e., non-movers) and mothers who give birth in a different state than their state-of-birth (i.e., movers). We report and discuss these results in Appendix C. The effects are very similar to the main results suggesting little concern over the influence of endogenous migration.

As a next step to evaluate the robustness of the results, we implement alternative sample selections and replicate the regressions. Specifically, we drop partially exposed cohorts, i.e., mothers born between 1952 and 1963, and focus on comparing fully exposed and unexposed mothers. The results are reported in panel D of Table 3. We observe slightly larger effects than the main results of Table 2. For instance, we observe a reduction in low birth weight by about 5.8 percent (versus 5.4 percent in Table 2). In Appendix I, we restrict the sample to narrower birth cohorts, mothers born between 1941-1970. The results become smaller than the main results due to limited variation in exposure but remain statistically and economically meaningful.

We further investigate the robustness of the results to alternative specifications in Appendix H. We allow time-invariant birth-state features to vary across mothers of different sociodemographic groups by interacting birth-state fixed effects with mothers' education, race, and age dummies. Moreover, we control for local policy, economic, and environmental influences in birth outcomes by including the county fixed effects interacted with year-month-of-birth fixed effects. In both models, the effects are almost identical to the main results.

5.4. Heterogeneity by Sociodemographic Characteristics

Several studies have documented the sociodemographic gap in birth outcomes and that the effects of maternal exposures on birth outcomes could be heterogenous based on maternal social class, human capital, and race (Noghanibehambari 2022; Florian, Ichou, and Panico 2021). Therefore, one would expect to observe the heterogeneous impacts of a healthier childhood on later-life health outcomes based on sociodemographic characteristics. For instance, low-educated mothers are more likely to reside in poorer neighborhoods and more polluted areas, less likely to have health insurance and healthcare access, and less aware of the causes and consequences of diseases (Banzhaf et al., 2019; Cutler & Lleras-Muney, 2010). All these factors contribute to the prevalence and severity of measles disease and point to larger benefits of vaccination for this subpopulation.

Table 4 Here

We explore this potential source of heterogeneity by replicating the main results among subpopulations of low-educated mothers (education $\leq$ 12 years of schooling) and high-educated mothers (education $>$ 12 years of schooling). The results are reported in panels A and B of Table 4, respectively. The marginal effects and implied percentage changes from the outcomes suggest larger impacts among low-educated mothers. For instance, the results suggest 7.6 grams of additional birth weight among low-educated mothers, roughly 30 percent larger than the marginal effect of birth weight in Table 2. This effect is also roughly twice the observed effect on birth weight among high-educated mothers. In Appendix Table J-1, we extend this table by showing the effects on mothers with 0-8, 9-12, and more than 12 years of schooling. For most outcomes, we observe larger changes from the mean in lower education groups. Moreover, we should note that adverse birth outcomes, such as preterm birth and low birth weight, are more prevalent among low-educated mothers. In both Table 4 and Appendix Table J-1, we find much larger effects on these adverse outcomes among low-educated mothers. In addition, we can rescale the observed effects based on pre-vaccine measles rates in high-measles states.[15] Full exposure to the vaccine among mothers with 0-8 and 9-12 years of schooling is associated with reductions in preterm birth by about 22.5 and 13.6 percent with respect to the mean of the outcome.

Another potential source of heterogeneity is based on the child's gender. While studies find that changes in maternal education and measures of socioeconomic status (as potential pathways in the current study, discussed in section 5.6) have differential impacts on male versus female

[15] While the 12-years average pre-vaccine measles rate is at roughly 924 per 100K, the average of above-median states stands at approximately 1450 per 100K population.

infants, the direction of the differential effects remains inconclusive. Some studies find larger effects among males (Clark, D'Ambrosio, and Rohde 2021), while others find the opposite (Chen et al. 2020). In Appendix B, we explore the heterogeneity in the results by infant gender. Although we find significantly larger effects on females, the differences in the marginal effects are very small.

5.5. Effects on Mortality and Fertility

So far, we have observed the direct long-run effects of the measles vaccine introduction. In this subsection, we explore the contemporaneous effects on mortality and fertility outcomes. In so doing, we construct a state-by-year panel between 1931 and 1980. The main independent variable of interest is the interaction between the pre-vaccine measles rate (as defined in equation 1) and a dummy indicating post-vaccine years. We implement regressions that include state and year fixed effects. The results are reported in Table 5. In column 1, we show the effect on the log of state-level measles rate (per 100K). Post-vaccine and for a state at the average pre-vaccine measles rate, the marginal effect suggests an average drop of about 28 percent. In column 2, we investigate the effects on state-level log infant mortality rate. We observe a reduction of 4.6 percent, consistent with several studies that suggest the benefits of the measles vaccine for infant and children mortality outcomes (Breiman et al. 2004).

Table 5 Here

Women's choice of maternity could be a function of their health and human capital. If higher exposure to measles/vaccination is correlated with this decision, and if this correlation varies by other maternal sociodemographic characteristics that also influence birth outcomes, then regressions of equation 1 are biased. To search for these sources of selective behavior, we explore the effects of measles vaccine exposure on measures of fertility and share of birth to different demographic groups. The results are reported in columns 3-5 of Table 5. We do not find statistically significant evidence for the endogenous selection of births. Specifically, we do not observe any association with the log of birth or the log of birth rate. We also do not find a significant correlation between the measles vaccine measure and the share of births to white mothers. Moreover, the estimated effects suggest quite small sizes, about a 0.36 percent reduction in births to white mothers. Since white mothers have, on average, healthier infants, the negative effects on the share of white mothers in the sample suggest that the estimated effects probably underestimate the true effects and offer a lower bound.

We should also note that this selective fertility analysis is based on contemporary data around the years of measles vaccination. Another source of endogenous fertility arises due to future fertility decisions among those exposed to measles during childhood. In Appendix K, we explain the reasons for this concern and the implications of this source of bias and empirically explore this issue. We find no evidence that exposure to measles during childhood is statistically associated with observable maternal characteristics of mothers. Hence, we also do not expect to find an association with unobservables (Altonji et al., 2005; Fletcher et al., 2021).

5.6. Potential Mechanisms

In section 2, we briefly reviewed the literature that has examined the effect of childhood health and later-life outcomes. Using these studies and pathway channels, we argued that measles vaccination provides a healthier childhood, improves health capital, raises physical growth, affects cognitive and non-cognitive outcomes, and improves educational attainment and labor market outcomes. We then built on these pathways to posit potential effects on maternal birth outcomes. In this section, we also add to this line of argument by empirically examining the impacts on a wide range of later-life socioeconomic outcomes, which have been shown to influence birth outcomes (Corman et al. 2019; Thorsen, Thorsen, and McGarvey 2019; Currie and Moretti 2003; Noghanibehambari, Salari, and Tavassoli 2022). We start by exploiting limited information available in the NCHS data on education, prenatal care utilization, and smoking behavior. We regress these outcomes on the exposure measures, conditional on fixed effects, trends, and birth-state covariates. The results are reported in Table 6. We observe a 2 percentage-points decrease in the probability of having less than 12 years of schooling (off a mean of 0.46) and a similar increase in having a college-and-more education (columns 1-2). Full exposure is associated with an 11 basis-points rise in the likelihood of having utilized any prenatal care, a 0.11 percent rise (column 3). Exposed mothers are also more likely to start prenatal care utilization in earlier pregnancy months (column 4). Finally, they are less likely to smoke during pregnancy, a reduction equivalent to 23 percent from the mean of the outcome (column 5).

Table 6 Here

We continue to explore mechanisms using alternative datasets. We pool decennial censuses 1970-2000 and American Community Survey (2001-2004) data files to cover a similar period as the main analysis sample. We restrict this sample to women aged 15-50 with a child under 2 years old in the household. We merge this pooled data with the measles rate database based on state-of-birth of individuals. We then implement regressions similar to equation 1, including birth-year fixed effects, birth-state fixed effects, birth-state trend, and current state-by-year fixed effects. The results are reported in Table 7. We observe 0.29 units increase in the socioeconomic score (column

1).[16] We find a 1.6 percent rise in employment (respective to the outcome mean, column 2). Further, we find a 6.7 percent increase in total personal income (column 3), an effect size larger than the findings of Atwood (2022). We also observe a 6 percent increase in house value and an insignificant 10 basis-point rise in the probability of being a homeowner (off a mean of 0.6) (columns 4-5). These improvements in socioeconomic status and income measures could partly operate as the pathways between measles vaccination and the next generations' birth outcomes (Barr, Eggleston, and Smith 2022; Hoynes, Miller, and Simon 2015; Lindo 2011). These effects are in line with several studies that examine later-life education-income effects of measles contraction and vaccination during childhood (Summan, Nandi, and Bloom 2022; Atwood 2022). These effects are also comparable to the findings of Schwandt (2017) that the contraction of flue during pregnancy is associated with reductions in income and education during adulthood.

Table 7 Here

In column 6, we find a reduction in Food Stamp recipiency due to measles vaccine exposure. The marginal effect, although statistically insignificant, implies a 25 percent drop from the mean of the outcome. This is also in-line with the results of Schwandt (2017) that reveal an increase of 35 percent in welfare dependency due to maternal influenza exposure during pregnancy.

In column 7, we find 86 basis-points reductions in the probability of having less than a high school education, a drop of 27 percent from the mean. This relatively large drop in low-educated

[16] The socioeconomic score in column 1 of Table 7 refers to Duncan Socioeconomic Index reported by (Ruggles et al. 2020). This measure is constructed using other measures of occupational education and income scores reported by the census (Duncan 1961).

mothers is informative of the potential pathways. Research has shown that the effects of education on such outcomes tend to be more significant for mothers with lower levels of education (Noghanibehambari, Salari, and Tavassoli 2022; Currie and Moretti 2003; Gage et al. 2013).

6. A Discussion on the Magnitude of the Results

To put the magnitude of the results into perspective, we can compare them with other policy interventions. For instance, Almond et al. (2011) explored the effect of the introduction of the Food Stamp program during the 1960s on birth outcomes. Their treatment-on-treated effects for participants suggested improvements in birth weight between 13-42 grams and reductions in low birth weight by 0.5-1.4 percentage-points. Comparing these effects with coefficients of Table 2 and assuming a midpoint effect in their estimations, our findings on birth weight and low birth weight account for 13-44 percent and 20-58 percent of the treatment-on-treated effects of the Food Stamp program, respectively. These are large impacts for two reasons. First, the effects of Table 2 are among the whole population and provide only intent-to-treat estimates. This aspect of our estimates can better be captured when we focus on the disadvantaged population (with potentially larger gains), as reported in Table 4. Moreover, we can use the estimated effect of column 1 of Table 5 as the benchmark first-stage effects to scale up the estimates. Therefore, we can calculate reductions in low birth weight and preterm birth by 20 and 21 percent, respectively. Second, our effects are assessed in the long-run and for the next generation, compared with the other contemporaneous policy-induced impacts on birth outcomes. Moreover, the measles vaccine has not been designed nor targeted at pregnant women. The results of our study suggest spillovers and externalities rather than direct planned and targeted policy effects.

Noghanibehambari (2022) examined the impacts of childhood exposure to the introduction of Medicaid during the 1960s on later-life maternal birth outcomes. He found that among nonwhite mothers born in states with average Medicaid eligibility, their newborns' birth weight increased by about 36 grams. Therefore, the intent-to-treat effect of measles vaccination for the next generation's birth weight is roughly 16 percent of the introduction of Medicaid, the largest federally funded social program in the US.

We can also focus on the documented later-life consequences of birth outcomes to understand the economic significance of the results. For instance, Almond et al. (2005) evaluated the extra hospital discharge costs associated with low birth weight. Their calculations suggested an average discharge cost of $13,200 related to low birth weight in excess of discharge costs related to normal birth weight (in 2020 dollars). In the year 2000, there were about 307K infants categorized as low birth weight. Table 2 suggests a 5.4 percent reduction in low birth weight, equivalent to 16,578 incidences in the year 2000. Using Almond et al. (2005) estimations, we reach a reduction of $218.8 million in hospital discharge costs due to the intergenerational benefits of measles vaccination.

7. Conclusion

This study joined the ongoing literature on intergenerational spillovers in health capital. We attempted to shed light on the intergenerational benefits of exposure to measles vaccination during childhood. We employed the universe of birth records in the US over the years 1970-2004. We implemented a difference-in-difference econometric method to explore the effect of mothers' childhood exposure to the measles vaccine on their future birth outcomes. We found that for mothers in states with an average pre-vaccine measles rate, fully exposed cohorts reveal roughly 6 grams of additional birth weight and 5 percent reductions in the incidence of low birth weight. These effects represented larger changes for adverse birth outcomes suggesting higher intergenerational benefits for mothers at higher pregnancy risks. Moreover, we observed larger effects among low-educated mothers. Further analyses suggest that improvements in educational outcomes, increases in prenatal care utilization, reductions in smoking, and increases in several measures of socioeconomic status are potential mechanism channels.

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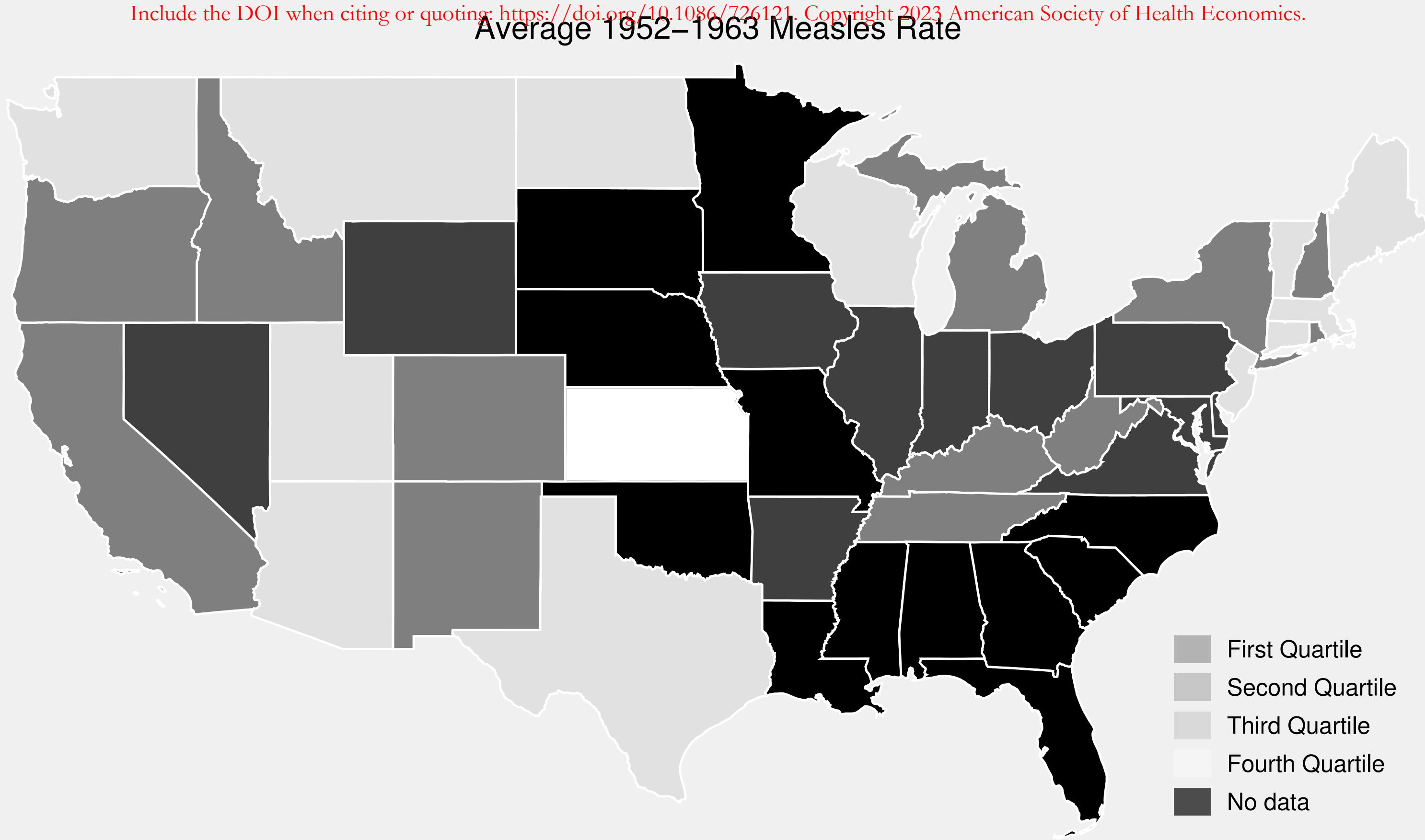
Figure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First Quartile
Second Quartile
Third Quartile
Fourth Quartile
No data

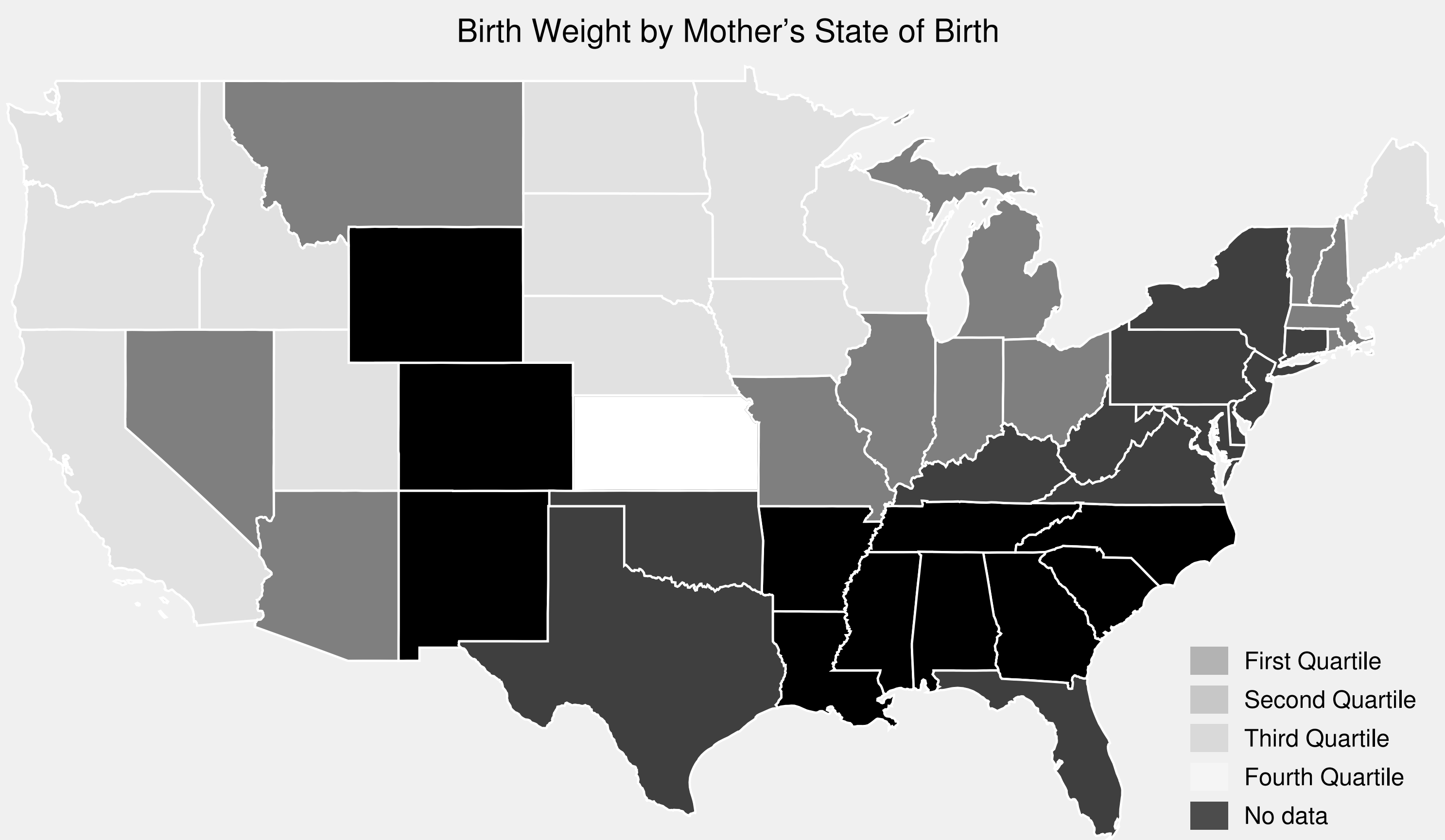
Birth Weight by Mother's State of Birth
First Quartile
Second Quartile
Third Quartile
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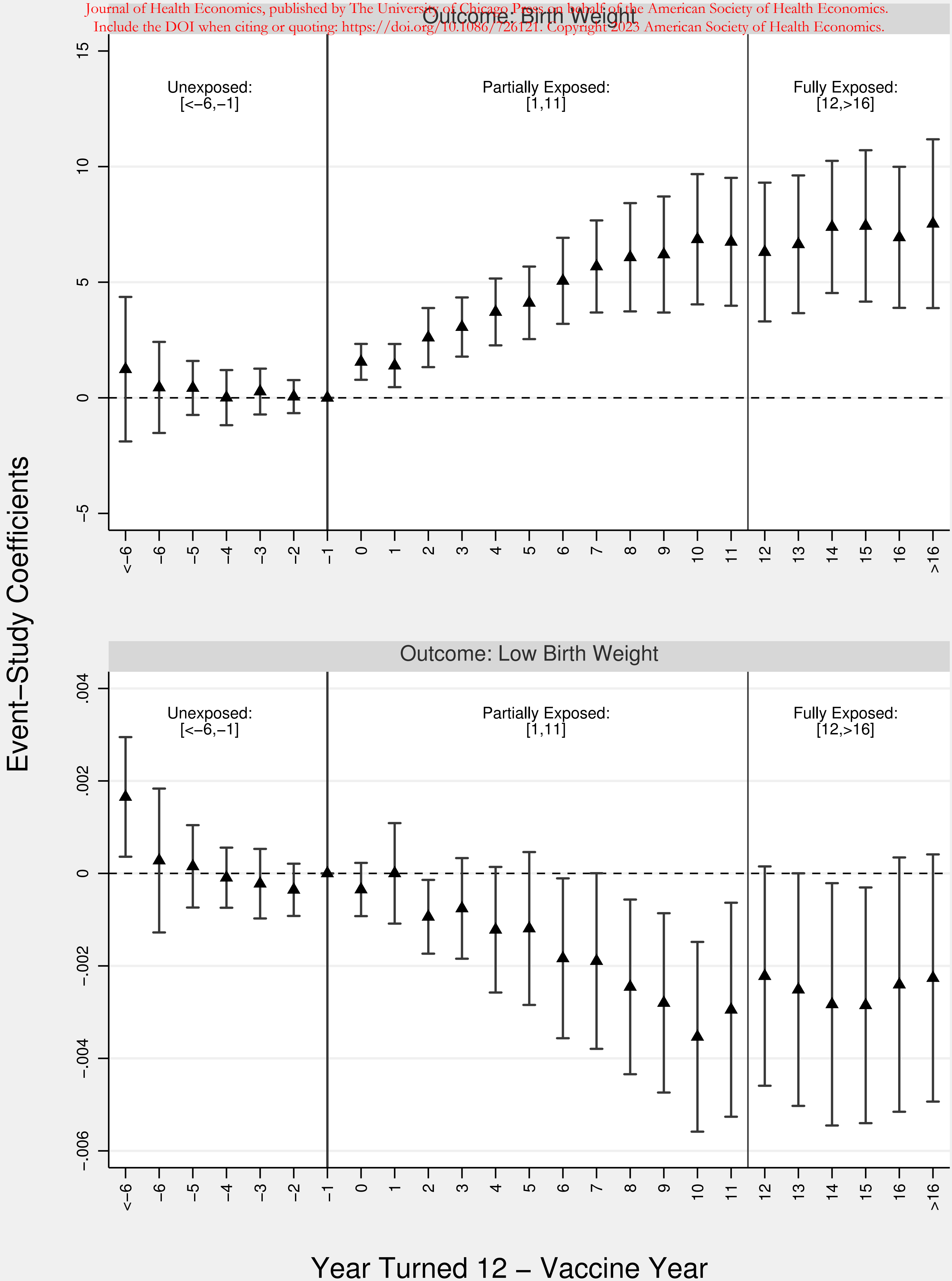
Figure Click here to access/download;Figure;fg2.eps



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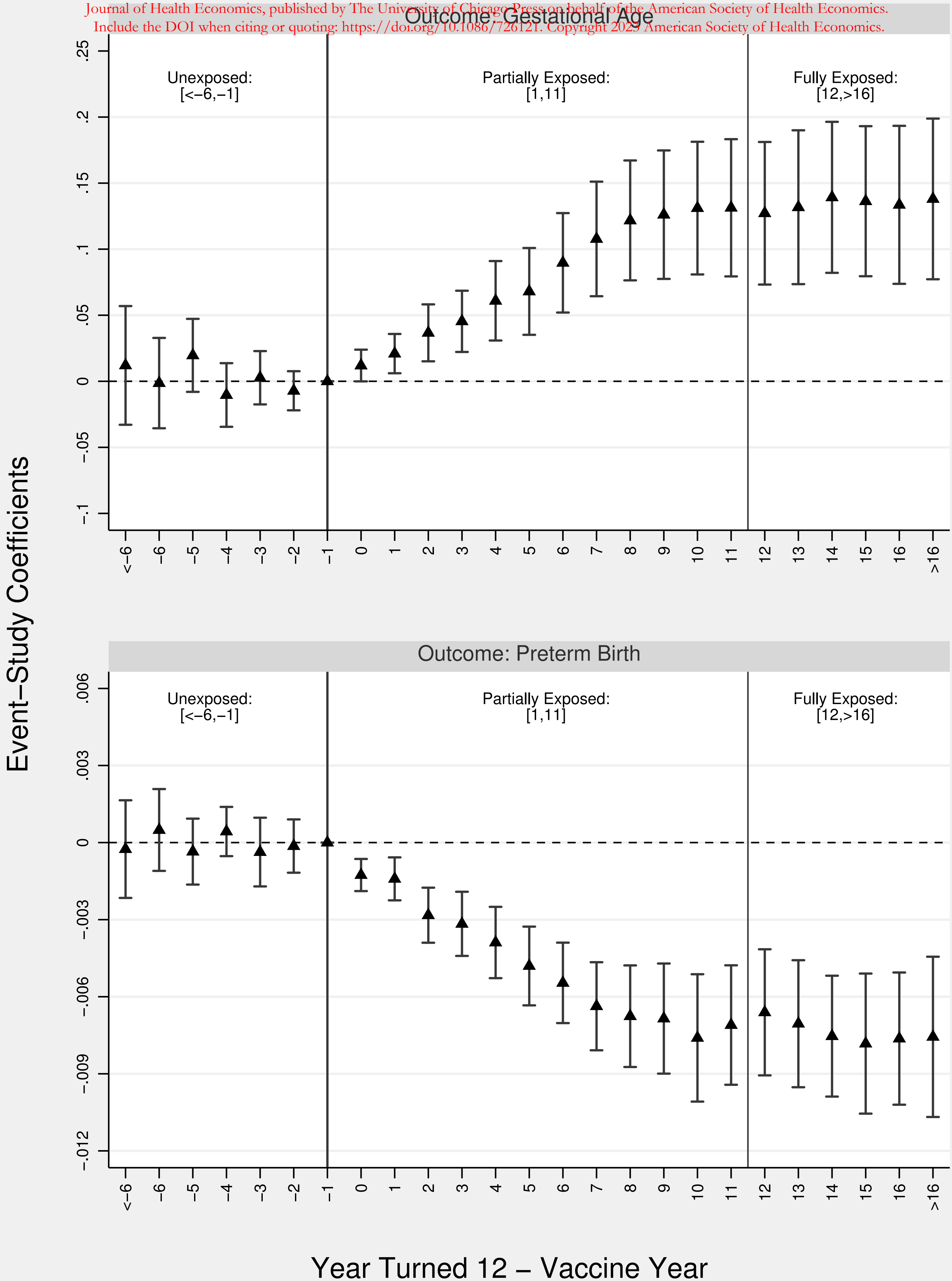

Outcome: Gestational Age
Unexposed: [<−6,−1]
Partially Exposed: [1,11]
Fully Exposed: [12,>16]
.25
.2
.15
.1
.05
0
-.05
-.1
Outcome: Preterm Birth
.006
.003
0
-.003
-.006
-.009
-.012
<−6 −6 −5 −4 −3 −2 −1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 >16
Event−Study Coefficients
Year Turned 12 – Vaccine Year

Figure

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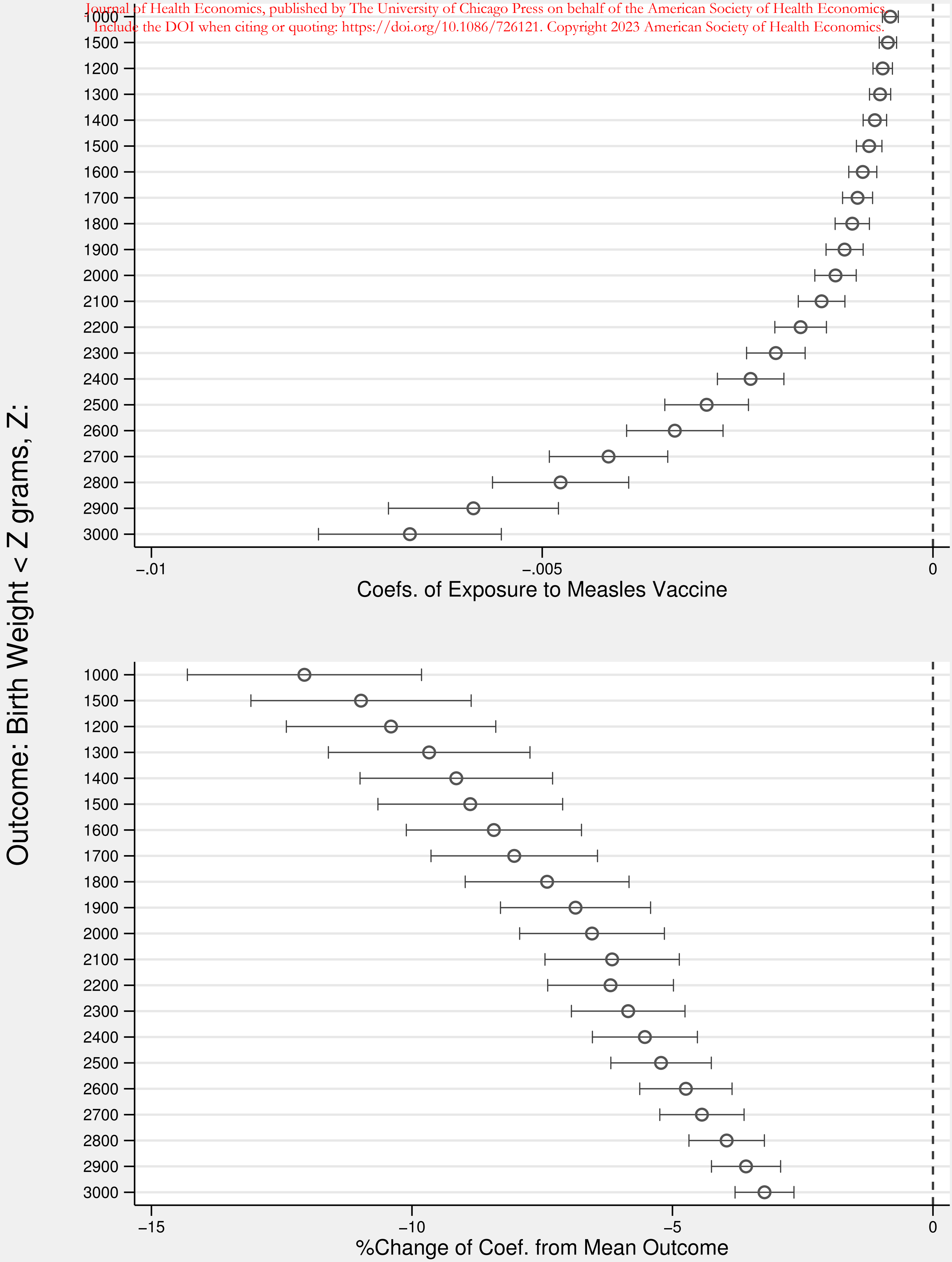

Table 1 - Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Child Characteristics:				
Birth Weight	3364.393	284.155	942.588	3572.004
Low Birth Weight	0.055	0.229	0	1
Very Low Birth Weight	0.009	0.095	0	1
Fetal Growth	86.046	13.67	4.904	352.778
Gestational Age	38.069	7.218	0	52
Preterm Birth	0.115	0.32	0	1
Child Female	0.488	0.5	0	1
Child First Born	0.29	0.454	0	1
12-Year Pre-Vaccine Measles Rate	924.896	538.158	91.343	2936.104
Share Childhood Exposure	0.715	0.372	0	1
Share Childhood Exposure × De-Meaned Pre-vaccine Measles Rate	0.72	0.598	0	3.196
Maternal Characteristics:				
Birth Year	1961.832	9.211	1931	1980
Year of Giving Birth	1989.101	8.937	1970	2004
Mother White	0.841	0.366	0	1
Mother Black	0.143	0.35	0	1
Mother Age	27.269	4.762	20	39
Mother Age 20-24	0.331	0.471	0	1
Mother Age 25-29	0.351	0.477	0	1
Mother Age 30-34	0.231	0.422	0	1
Mother Age 35-39	0.086	0.281	0	1
Mother Education<High School	0.1	0.3	0	1
Mother Education High School	0.462	0.499	0	1
Mother Education Some College	0.219	0.413	0	1
Mother Education Bachelor-above	0.219	0.414	0	1
Any Prenatal Visits	0.917	0.276	0	1
Observations	73,932,418			

Notes. The data is extracted from NCHS (2020) and covers births between 1970-2004. Low birth weight is a dummy indicating birth weight of less than 2,500 grams. Very low birth weight is a dummy indicating birth weight of less than 1,500 grams. Preterm birth is a dummy indicating gestational age of less than 37 weeks. Fetal growth is calculated by dividing birth weight by gestational age.

Table 2 - Main Results: The Association between Childhood Exposure to Measles Vaccination and Birth Outcomes

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	5.84403***	-0.00298**	-0.00069**	0.15271	0.13329***	-0.00655***
	(1.46155)	(0.00125)	(0.00029)	(0.12255)	(0.03185)	(0.00126)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	0.03027	0.01667	0.00623	0.05512	0.84706	0.24521
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.174	-5.422	-7.661	0.177	0.350	-5.693

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Table 3 - Robustness Checks to Alternative Specifications

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Adding Mother's Region-of-Birth-by-Birth-Year Fixed Effects						
Share Childhood Exposure	4.87194***	-0.00244***	-0.00051***	0.12501***	0.13301***	-0.00581***
× Pre-vaccine Measles Rate	(0.51723)	(0.00035)	(0.00012)	(0.02792)	(0.01226)	(0.00052)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	0.03028	0.01668	0.00623	0.05515	0.84706	0.24521
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.145	-4.428	-5.684	0.145	0.349	-5.056
Panel B. Adding Mortality Rates in State-Year of Birth of Mother						
Share Childhood Exposure	5.92649***	-0.00296***	-0.00067***	0.13712***	0.14146***	-0.00676***
× Pre-vaccine Measles Rate	(0.5685)	(0.0004)	(0.00013)	(0.03254)	(0.01051)	(0.00054)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	0.03043	0.0168	0.00627	0.05541	0.84734	0.24536
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.176	-5.377	-7.403	0.159	0.372	-5.883
Panel C. Adding Mother's Birth-State by State-of-Residence Fixed Effects						
Share Childhood Exposure	5.89036***	-0.003***	-0.00068***	0.16236***	0.12978***	-0.00651***
× Pre-vaccine Measles Rate	(0.56801)	(0.0004)	(0.00013)	(0.03233)	(0.01059)	(0.00053)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	0.03055	0.01679	0.00629	0.05542	0.84717	0.24544
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.175	-5.461	-7.587	0.189	0.341	-5.662
Panel D. Excluding Partially Exposed Cohorts						
Share Childhood Exposure	6.48372***	-0.00333***	-0.00095***	0.23701***	0.13895***	-0.00689***
× Pre-vaccine Measles Rate	(0.67605)	(0.00048)	(0.00016)	(0.0391)	(0.01489)	(0.00063)
Observations	47276779	47276779	47276779	45752904	47276779	47276779
R-squared	0.02852	0.01619	0.00639	0.05429	0.85316	0.24403
Mean DV	3356.015	0.057	0.010	86.000	37.899	0.121
%Change	0.193	-5.850	-9.515	0.276	0.367	-5.690

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** p<0.01, ** p<0.05, * p<0.1

Table 4 - Heterogeneity of the Results across Subsamples

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Low Educated Mothers (Education≤ 12 years):						
Share Childhood Exposure × Pre-vaccine Measles Rate	7.58801***	-.005***	-.00097***	.27127***	.16996***	-.00827***
	(.78056)	(.00058)	(.00019)	(.04199)	(.01488)	(.00076)
Observations	41555092	41555092	41555092	39600577	41555092	41555092
R-squared	.03254	.01704	.00671	.04724	.87966	.30866
Mean DV	3357.162	0.064	0.010	85.038	37.435	0.139
%Change	0.226	-7.816	-9.722	0.319	0.454	-5.948
Panel B. High Educated Mothers (Education> 12 years):						
Share Childhood Exposure × Pre-vaccine Measles Rate	3.81116***	-.00122***	-.00043***	.04253	.08217***	-.00458***
	(.55172)	(.00039)	(.00016)	(.02951)	(.00901)	(.00055)
Observations	32377321	32377321	32377321	32072363	32377321	32377321
R-squared	.02534	.01215	.00524	.05246	.69103	.10686
Mean DV	3373.673	0.045	0.008	87.291	38.882	0.085
%Change	0.113	-2.719	-5.436	0.049	0.211	-5.385
P-Value of the Differencee between Coefficients of Panel A and B	0.000	0.000	0.000	0.000	0.000	0.000

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** p<0.01, ** p<0.05, * p<0.1

Table 5 - Exploring the Effects on Measles Rates, Infant Mortality, and Selective Fertility

	Outcomes:				
	Log Measles Rate	Log Infant Mortality Rate	Log Birth Counts	Log Birth Rate	Share of Births to White Mothers
	(1)	(2)	(3)	(4)	(5)
I(year>1963) × Pre-vaccine Measles Rate	-.27568***	-.04608***	-.01219	-.00863	-.00304
	(.08177)	(.01576)	(.04074)	(.01356)	(.00681)
Observations	1163	1850	2417	2084	2417
R-squared	.87131	.96611	.99071	.92273	.97763
Mean DV	5.467	3.889	11.030	7.644	0.841
%Change	-5.043	-1.185	-0.111	-0.113	-0.362

Notes. Standard errors, two-way clustered at the state and year, are in parentheses. All regressions are weighted using the total birth count in each state-year. All regressions include state and year fixed effects and a state linear trend.
*** p<0.01, ** p<0.05, * p<0.1

Table 6 - Exploring Mechanism Channels Using Information in NCHS Data

	Outcomes:				
	Education < 12	Education: College-More	Any Prenatal Care During Pregnancy	Pregnancy-Month that Prenatal Care Began	Is Mom Smoker
	(1)	(2)	(3)	(4)	(5)
Share Childhood Exposure × Pre-vaccine Measles Rate	-.02053***	.01991***	.00112***	-.03092***	-.01748***
	(.00562)	(.00556)	(.0002)	(.00599)	(.00212)
Observations	73932418	73932418	67933302	67551757	73932418
R-squared	.22466	.21953	.01867	.10113	.13849
Mean DV	0.464	0.438	0.994	2.546	0.077
%Change	-4.424	4.546	0.113	-1.215	-22.706

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children.

*** p<0.01, ** p<0.05, * p<0.1

Table 7 - Exploring Mechanism Channels Using Census-ACS Data

	Outcomes:						
	Socioeconomic Score	Is Employed	Log Total Income	Log House Value	House Owner	Food Stamp Recipient	Education < High School
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Share Childhood Exposure × Pre-vaccine Measles Rate	.29099*	.00756**	.06689***	.06068***	.00105	-.03559	-.00859***
	(.16086)	(.0035)	(.01174)	(.0088)	(.0038)	(.0529)	(.00204)
Observations	881286	1031751	729154	590169	1031751	107733	1031751
R-squared	.11746	.09441	.33784	.6104	.15313	.12212	.05197
Mean DV	45.857	0.461	8.888	11.364	0.615	0.140	0.032
%Change	0.635	1.640	0.753	0.534	0.171	-25.419	-26.845

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children.
*** p<0.01, ** p<0.05, * p<0.1

Appendixes for: Intergenerational Benefits of Childhood Health Intervention: Evidence from Measles Vaccination

Hamid Noghanibehambari

Appendix Table of Contents

Appendix A

In the main text, we use two-way clustering by mothers' birth state and birth year to adjust standard errors. In Appendix Table A-1, we explore the sensitivity of the results to alternative methods of fixing standard errors. We use Huber-White robust standard errors in panel A. We then implement clustering at birth-state in panel B. We observe a very similar pattern of statistical significance as the main results.

Appendix Table A-1 - Robustness of Standard Errors to Alternative Clustering Levels

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Using Huber-White Robust Standard Errors						
Share Childhood Exposure × Pre-vaccine Measles Rate	5.84403***	-0.00298***	-0.00069***	0.15271***	0.13329***	-0.00655***
	(0.34932)	(0.00029)	(0.00012)	(0.01751)	(0.00387)	(0.00035)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	0.03027	0.01667	0.00623	0.05512	0.84706	0.24521
Panel B. Clustering at Mother's State-of-Birth Level						
Share Childhood Exposure × Pre-vaccine Measles Rate	5.84403***	-0.00298**	-0.00069**	0.15271	0.13329***	-0.00655***
	(1.46155)	(0.00125)	(0.00029)	(0.12255)	(0.03185)	(0.00126)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	0.03027	0.01667	0.00623	0.05512	0.84706	0.24521

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** p<0.01, ** p<0.05, * p<0.1

Appendix B

In Appendix Table B-1, we explore the heterogeneity of the results based on the child's gender. We find quite similar effects for both genders, suggesting little heterogeneity based on the child's gender. Morover, the tests of equality of coefficients across panels suggest statistically insignificant differences.

Appendix Table B-1 - Heterogeneity of the Effects by Child Gender

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Female Infants						
Share Childhood Exposure × Pre-vaccine Measles Rate	6.20396***	-.00316***	-.00071***	.1634***	.13636***	-.00643***
	(.63739)	(.0005)	(.00017)	(.03599)	(.01163)	(.00061)
Observations	36054717	36054717	36054717	34955375	36054717	36054717
R-squared	.03215	.01799	.00645	.03959	.84941	.2563
Mean DV	3370.663	0.060	0.009	84.287	38.131	0.111
%Change	0.184	-5.268	-7.937	0.194	0.358	-5.792
Panel B. Male Infants						
Share Childhood Exposure × Pre-vaccine Measles Rate	5.58068***	-.00285***	-.00068***	.14474***	.13219***	-.00674***
	(.66333)	(.00047)	(.00018)	(.0391)	(.0115)	(.00064)
Observations	37877693	37877693	37877693	36717562	37877693	37877693
R-squared	.02786	.01468	.00607	.04058	.84483	.23512
Mean DV	3358.424	0.051	0.009	87.721	38.009	0.120
%Change	0.166	-5.590	-7.504	0.165	0.348	-5.619
P-Value of the Differencee between Coefficients of Panel A and B	0.342	0.577	0.864	0.605	0.553	0.630

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** p<0.01, ** p<0.05, * p<0.1

D

Appendix C

One concern in interpreting the main results of the paper is regarding endogenous migration. Parents may choose to migrate after giving birth for various reasons, including the prevalence of measles. Since local-level confounders could influence birth outcomes, the residential location choice could be determined endogenously. In panel C of Table 3, we interact birth-state and state-of-residence to limit the variations to movers and non-movers groups. In this appendix, we show the main results among movers, i.e., those whose state-of-birth differs from state-of-giving-birth, and non-movers, i.e., those who gave birth in their own state-of-birth. We should note that about 65.9 percent of observations are non-movers and 34.1 percent are movers. The results are reported in Appendix Table C-1 and Appendix Table C-2 for non-movers and movers, respectively. We find quite similar results across both subsamples suggesting little concerns over endogenous migration.

Appendix Table C-1 - Replicating the Main Results among Mothers who Gave Birth in the same State as their own Birth-State (Non-Movers Subsample)

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	5.58168***	-.0025***	-.00046***	.14784***	.04487***	-.00453***
	(.74258)	(.00053)	(.00017)	(.04153)	(.00748)	(.00066)
Observations	48752499	48752499	48752499	47138612	48752499	48752499
R-squared	.03217	.01776	.00666	.05531	.86693	.25813
Mean DV	3361.060	0.058	0.010	85.852	37.947	0.121
%Change	0.166	-4.312	-4.551	0.172	0.118	-3.742

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table C-2 - Replicating the Main Results among Mothers who Gave Birth in a different State than their own Birth-State (Movers Subsample)

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	5.75687***	-.00279***	-.00081***	.07778**	.14191***	-.00674***
	(.66402)	(.00048)	(.0002)	(.03635)	(.01225)	(.00065)
Observations	25179904	25179904	25179904	24534318	25179904	25179904
R-squared	.02596	.01422	.00533	.05419	.80010	.21641
Mean DV	3370.846	0.052	0.008	86.419	38.304	0.105
%Change	0.171	-5.370	-10.121	0.090	0.370	-6.422

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix D

In the main results, we control for several birth-state characteristics using decennial censuses and interpolating for inter-decennial years. In Appendix Table D-1, we use the state characteristics in the nearest census as covariates in our regressions. The estimated effects are only slightly larger than those in the main results of Table 2.

Appendix Table D-1 - Replicating the Main Results using the Birth-State Characteristics in the Nearest-Census Census as Cova

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	6.71419***	-.00345***	-.0008***	.21318***	.13483***	-.00685***
	(.5816)	(.00041)	(.00013)	(.03282)	(.01097)	(.00054)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	.03027	.01667	.00623	.05511	.84706	.24521
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.200	-6.275	-8.887	0.248	0.354	-5.959

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix E

In the main results, we use mothers' birth-state variable as a proxy for the state in which they spent their childhood and probably received the measles vaccine. However, this variable has a missing value in roughly 2.9 percent of mothers (about 2.3 million mothers). This missing value issue is observed among a subpopulation of mothers in every state for pre-1980 years. In this appendix, we use the reported information on the state-of-residence of the mother (i.e., the state in which they give birth) as a proxy for state-of-birth for this subsample of mothers. We replicate the main results in Appendix Table E-1. We observe very similar coefficients as those reported in the main results of the paper, suggesting that missingness in the variable is less likely to be an issue.

Appendix Table E-1 - Replicating the Main Results Using Mother's State-of-Residence as a Proxy for Mother's Birth-State in cases of Missing Values for Birth-State

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood	5.9849***	-.00303***	-.00066***	.15584***	.1323***	-.00663***
Exposure × Pre-vaccine Measles Rate	(.56702)	(.00039)	(.00013)	(.03251)	(.01103)	(.00053)
Observations	76212607	76212607	76212607	73438357	76212607	76212607
R-squared	.03003	.0163	.00611	.05474	.8636	.27711
Mean DV	3363.368	0.055	0.009	86.013	37.844	0.121
%Change	0.178	-5.504	-7.351	0.181	0.350	-5.483

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix F

The variable $ShareEXP$ in equation 1, our primary independent variable of interest, measures the share of exposure during childhood up to age 12. In this appendix, we explore the robustness to this age cut-off. We use an age cut-off of 6 years as an alternative threshold and replicate the results in Appendix Table F-1. We find slightly smaller effects compared with those in Table 2. This is expected given the fact that some of the children may have received the vaccine after age 6 and still benefited from it but are now in the control group. To further probe this robustness practice, we use four age-at-exposure groups to be able to observe the effects across different ages at exposure. These groups include those who were born in 1963 and after (exposure from birth), those ages 1-6, those ages 7-12, and finally, ages 13 and more. Using the last group as the reference group, we show the results in Appendix Table F-2. We find that those exposed from birth (first group) to age 6 (second group) reveal consistently larger marginal effects than those with age-at-exposure of 7-12. This pattern implies the relevance of childhood exposure to the vaccine rather than later ages, as we have expected a priori.

Appendix Table F-1 - Robustness of Exposure Measure: Using the first Six Years of Life as the Exposure Years

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	4.47453*** (.38985)	-.00241*** (.0003)	-.0005*** (.0001)	.13372*** (.02386)	.09391*** (.01014)	-.00556*** (.0004)
Observations	76212606	76212606	76212606	73438356	76212606	76212606
R-squared	.03003	.0163	.00611	.05474	.8636	.27712
Mean DV	3363.368	0.055	0.009	86.013	37.844	0.121
%Change	0.133	-4.373	-5.596	0.155	0.248	-4.596

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** p<0.01, ** p<0.05, * p<0.1

Appendix Table F-2 - Robustness of Exposure Measure: Measuring Exposure across different Age Groups

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Exposure during Prenatal Period × Pre-vaccine Measles Rate	5.51512*** (.63802)	-.00193*** (.00048)	-.00055*** (.00015)	.06999* (.03961)	.11044*** (.01424)	-.0061*** (.00066)
Share Exposure during Age 1-6 × Pre-vaccine Measles Rate	4.83594*** (.45725)	-.00238*** (.00035)	-.00053*** (.00011)	.11951*** (.02826)	.10273*** (.01155)	-.00582*** (.00047)
Share Exposure during Age 7-12 × Pre-vaccine Measles Rate	2.29308*** (.35898)	-.00088*** (.00025)	-.00021** (.00008)	.04255* (.02313)	.03975*** (.00898)	-.003*** (.00039)
Observations	76212606	76212606	76212606	73438356	76212606	76212606
R-squared	.03003	.0163	.00611	.05474	.8636	.27711
Mean DV	3363.368	0.055	0.009	86.013	37.844	0.121

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** p<0.01, ** p<0.05, * p<0.1

Appendix G

The variable $Measles^{*}$ in equation 1 is calculated using a 12-years average of measles rate in birth-state, i.e., the years 1952-1963. This is because the measles incidence reported by the CDC's Morbidity and Mortality Weekly Reports Annual Supplement started in 1952. However, we explore the robustness of the results to alternative year windows to calculate pre-vaccine measles rates. We use the 3-year, 6-year, and 9-year average measles rate prior to vaccine introduction and replicate the results in three panels of Appendix Table G-1. We observe comparable effects across three measures, although the effects are slightly larger as we expand the window of calculating the average value.

Appendix Table G-1 - Using the past 3-Years Birth-State Measles Rate to Calculate Exposure Measure

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A.						
Share Childhood Exposure × 3-Years Pre-vaccine Measles Rate	4.30053***	-.00232***	-.00051***	.12681***	.08596***	-.00449***
	(.37496)	(.00027)	(.00009)	(.02265)	(.00899)	(.00038)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	.03027	.01667	.00623	.05512	.84706	.2452
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.128	-4.213	-5.636	0.147	0.226	-3.908
Panel B.						
Share Childhood Exposure × 6-Years Pre-vaccine Measles Rate	4.92607***	-.0025***	-.00056***	.10022***	.10495***	-.00529***
	(.43398)	(.00031)	(.0001)	(.0265)	(.00934)	(.00042)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	.03027	.01667	.00623	.05512	.84706	.24521
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.146	-4.549	-6.186	0.116	0.276	-4.598
Panel C.						
Share Childhood Exposure × 9-Years Pre-vaccine Measles Rate	5.62261***	-.00284***	-.00065***	.12646***	.12623***	-.0062***
	(.55996)	(.0004)	(.00013)	(.03274)	(.01081)	(.00053)
Observations	73932418	73932418	73932418	71672945	73932418	73932418
R-squared	.03027	.01667	.00623	.05512	.84706	.2452
Mean DV	3364.393	0.055	0.009	86.046	38.069	0.115
%Change	0.167	-5.169	-7.198	0.147	0.332	-5.393

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix H

In this appendix, we further explore the robustness of the results to the inclusion of a stricter set of covariates. We allow the fixed effects of birth-state to vary flexibly by maternal education, age, and race. Therefore, we allow the birth-state unobserved time-invariant confounders to be different across people of different sociodemographic groups. The results, reported in Appendix Table H-1, are quite similar to the main results of Table 2.

Another concern is the influence of contemporaneous confounders related to local economic, policy, and environmental conditions and seasonal influences. To account for these factors, we include the county-of-resdience of the mother (county-of-birth of the infant) fixed effects and interact them with infants' year-month of birth. The results are reported in Appendix Table H-2 and imply a similar pattern as those in Table 2.

Appendix Table H-1 - Interactin Mother's Birth-State Fixed Effects by Race, Age, and Education Dummies

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	5.15394***	-.00243***	-.00048***	.11393***	.09341***	-.00481***
	(.53593)	(.00038)	(.00013)	(.03142)	(.0073)	(.0005)
Observations	73570090	73570090	73570090	71478766	73570090	73570090
R-squared	.04727	.03283	.02069	.07276	.84954	.24761
Mean DV	3364.483	0.055	0.009	86.049	38.155	0.113
%Change	0.153	-4.417	-5.346	0.132	0.245	-4.261

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix Table H-2 – Adding Child's County-of-Birth by Year-Month-of-Birth Fixed Effects

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	5.72248***	-.00295***	-.00066***	.14779***	.10523***	-.00568***
	(.55138)	(.00039)	(.00013)	(.03205)	(.00783)	(.00051)
Observations	73570090	73570090	73570090	71478766	73570090	73570090
R-squared	.04714	.03272	.02065	.07247	.84935	.24748
Mean DV	3364.483	0.055	0.009	86.049	38.155	0.113
%Change	0.170	-5.358	-7.353	0.172	0.276	-5.028

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix I

In the main results, we use cohorts of mothers born between 1931-1980. In this appendix, we restrict this cohort variation to include a narrower set of cohorts, those born between 1941-1970. We report the results in Appendix Table I-1. Although the marginal effects become relatively smaller than the main results, they remain economically and statistically significant.

Appendix Table I-1 - Restricting the Sample to Mothers Born Between 1940-1970

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	4.13101***	-.00223***	-.00033*	.12734***	.13254***	-.0053***
	(.79862)	(.00051)	(.00017)	(.04246)	(.01558)	(.00078)
Observations	61035591	61035591	61035591	58968790	61035591	61035591
R-squared	.03113	.01745	.00631	.05617	.85653	.2714
Mean DV	3369.716	0.054	0.009	86.187	38.005	0.115
%Change	0.123	-4.121	-3.630	0.148	0.349	-4.608

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix J

In Table 4, we showed the results across subsamples of low-educated (education ≤ 12) and high-educated (education > 12) mothers. In this appendix, we split the sample into three groups to further explore this source of heterogeneity. We show the results among mothers with 0-8 years of schooling, 9-12 years of schooling, and more than 12 years of schooling. The results are reported in Appendix Table J-1. Since each group has a different mean across outcomes, we focus on the implied percentage change from the mean reported in the last row of each column. For birth weight, very low birth weight, fetal growth, and preterm birth, we observe larger effects among mothers with 0-8 years of schooling compared with those 9-12 years of schooling. For low birth weight and gestational length, the latter group reveals larger effects than the former. For all outcomes, we observe much larger impacts among the 0-8 and 9-12 years of schooling groups than those with more than 12 years of education.

Appendix Table J-1 - Exploring The Heterogeneity by Maternal Education

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Mother's Education 0-8 Years						
Share Childhood	10.79242	-.00514	.0023	-1.28864*	.20127	-.01757
Exposure × Pre-vaccine Measles Rate	(15.0659)	(.01273)	(.00485)	(.68111)	(.13458)	(.0138)
Observations	152679	152679	152679	152376	152679	152679
R-squared	.04433	.03577	.02061	.07099	.30679	.04587
Mean DV	3328.163	0.077	0.013	84.807	38.812	0.116
%Change	0.324	-6.675	17.719	-1.519	0.519	-15.150
Panel B. Mother's Education 9-12 Years						
Share Childhood	9.12495***	-.00641***	-.00125***	.41683***	.20226***	-.01036***
Exposure × Pre-vaccine Measles Rate	(.78163)	(.0006)	(.00021)	(.038)	(.01523)	(.00077)
Observations	34155834	34155834	34155834	33621037	34155834	34155834
R-squared	.03267	.01744	.00681	.04649	.73428	.1362
Mean DV	3355.310	0.066	0.011	84.874	38.631	0.113
%Change	0.272	-9.719	-11.343	0.491	0.524	-9.164
Panel C. Mother's Education > 12 Years						
Share Childhood	3.81116***	-.00122***	-.00043***	.04253	.08217***	-.00458***
Exposure × Pre-vaccine Measles Rate	(.55172)	(.00039)	(.00016)	(.02951)	(.00901)	(.00055)
Observations	32377321	32377321	32377321	32072363	32377321	32377321
R-squared	.02534	.01215	.00524	.05246	.69103	.10686
Mean DV	3373.673	0.045	0.008	87.291	38.882	0.085
%Change	0.113	-2.719	-5.436	0.049	0.211	-5.385

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1

Appendix K

One concern in interpreting the main results is the selective selection of mothers into the maternity ward. For instance, it could be the case that black mothers show higher fertility during adulthood and are more likely to enter into maternity (hence our sample) as a result of improvements in health and human capital during childhood. Black mothers have, on average, worse birth outcomes for unobserved reasons. Hence, the coefficients underestimate the true effects as the sample contains an endogenously higher black mother. To explore this source of endogeneity, we regress several maternal observable characteristics on our exposure measures, conditional on fixed effects, trends, and birth-state covariates. The results are reported in Appendix K. We observe small and insignificant coefficients for the child's gender, the mother's race, age group, and the child's birth order. Finally, we construct a birth weight index that can be explained by these observable characteristics. In so doing, we regress birth weight on maternal age, race, and education and the child's gender and parity. We use the predicted value of this regression to observe the effects on a portion of the main outcome that can be explained and predicted by observable maternal characteristics. The results, reported in column 9, suggest a change of 0.04 percent with respect to the mean of the outcome. This effect is economically and statistically insignificant.

Appendix Table K-1 - Balancing Tests

	Outcomes:								
	Child Female	Mother White	Mother Black	Mother Age 20-25	Mother Age 26-30	Mother Age 31-35	Mother Age 36-40	Birth Order	Birth Weight Index
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Share Childhood Exposure × Pre-vaccine Measles Rate	-.0005922	-.0092885	-.0108371	.0110703	.0070621	-.0111875	.0002248	.0039006	-1.2551368
	(.0004669)	(.0184342)	(.0113131)	(.0108632)	(.009563)	(.0157579)	(.0021083)	(.0055847)	(1.0319327)
Observations	73932415	73500973	73932415	73932415	73932415	73932415	73932415	73932415	73932415
R-squared	.0000337	.1176519	.1259325	.1340667	.5939113	.030136	.2752332	.3752359	.124026
Mean DV	0.488	2.456	0.841	0.143	0.331	0.351	0.231	0.086	3364.393
%Change	-0.121	-0.378	-1.289	7.741	2.134	-3.187	0.097	4.536	-0.037

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children.
*** p<0.01, ** p<0.05, * p<0.1

Appendix L

As described in section 3, we restrict the final sample to mothers aged 19-40 to avoid complications of teenage and advanced-age maternity. In Appendix Table L-1, we replicate the main results without this sample restriction. The effect on birth weight rises by about 55 percent. However, the effects on adverse birth outcomes are more comparable to the main results. Focusing on implied percentage changes, the effects on low birth weight, very low birth weight, and preterm birth decreases by about 3.9, 6.7, and 7.6 percent, while in Table 2, we observed reductions of 5.4, 7.7, and 5.7 percent. Overall, these effects are still economically and statistically meaningful.

Appendix Table L-1 - Robustness to the Original NCHS Sample without Maternal Age Restrictions

	Outcomes:					
	Birth Weight	Low Birth Weight	Very Low Birth Weight	Fetal Growth	Gestational Age	Preterm Birth
	(1)	(2)	(3)	(4)	(5)	(6)
Share Childhood Exposure × Pre-vaccine Measles Rate	9.13185***	-.0024***	-.00067***	.12574***	.14993***	-.00937***
	(.57291)	(.00036)	(.00012)	(.02837)	(.00874)	(.00054)
Observations	89264063	89264063	89264063	86432537	89264063	89264063
R-squared	.03159	.01781	.00652	.05919	.84446	.23825
Mean DV	3356.790	0.061	0.010	85.488	37.976	0.124
%Change	0.272	-3.936	-6.691	0.147	0.395	-7.559

Notes. Standard errors, two-way clustered at the mother's state-of-birth and year-of-birth, are in parentheses. All regressions include the mother's state-of-birth fixed effects, year-of-birth fixed effects, state-of-birth linear trend in year-of-birth, and state-of-residence by year fixed effects. The regressions also include controls for maternal age, maternal education, maternal race, maternal ethnicity, child's gender, birth parity, and prenatal visits. The regressions include birth-state-year controls extracted from decennial censuses and interpolated for inter-decennial years. These controls include average socioeconomic index, female labor force participation rate, literacy rate, share of married individuals, and the average number of children. *Birth weight* is the weight of infant at birth and measured in grams. *Low birth weight* is a binary outcome that turns on if birth weight is less than 2,500 grams. *Very low birth weight* is a binary outcome that turns on if birth weight is less than 1,500 grams. *Fetal growth* is gain in weight per each week of gestation, i.e., birth weight divided by gestational weeks. *Gestational age is* the clinical estimation of the period between conception and birth. Preterm birth is a dummy that equals one if gestational age is less than 37 weeks.
*** p<0.01, ** p<0.05, * p<0.1