“FACTORS AFFECTING IMMUNIZATION COVERAGE, 1999-2008:
A NATIONWIDE ASSESSMENT USING A DELAY-BASED APPROACH”

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INTRODUCTION

Childhood immunizations are critical for sound public health. The Centers for Disease Control and Prevention (CDC) and public health policymakers keep childhood vaccination coverage at the forefront of child health initiatives. The CDC recommends a series of childhood immunizations consisting of 14 vaccinations that must be received before two years of age. This regimen is commonly referred to as the 4:3:1:3:3 series because it consists of four doses for diptheria-tetanus-pertussis (DTP4), three of oral poliovirus vaccine (Polio3), one for measles-mumps-rubella (MMR1), three for *Haemophilus influenzae* type b (Hib), and three for hepatitis B (HepB). Additionally, the CDC provides an annually updated immunization schedule that providers and caretakers are to follow for both adequate and timely immunization (CDC 2008).

The benefits of achieving up-to-date (UTD) status include not only individual resistance against disease, but prevention of outbreaks that could otherwise affect the public at large. A noteworthy case in point is the beneficial effect of the poliovirus vaccine. Provisions of the vaccine, beginning in 1963, were made to tackle the incidence of polio. In 1960, there were 2,525 cases within the United States. Within 5 years, there were merely 61 and by the 1990s, the once crippling polio virus became, more or less, a worry of the past (CDC 2010). However, polio is innocuous because of high immunization coverage – not natural immunity. Thus, the establishment of high UTD coverage was certainly monumental but maintaining it remains an equally important matter.

Additionally, delays in receipt of vaccinations, which is also referred to as underimmunization, is a concern for policymakers though a child may eventually become UTD. First and foremost, timely vaccination protects children from diseases when they are most vulnerable. For instance, a three-year study in Canada determined that 20 of the 29 cases (69%)

of *H. influenzae* type b infections occurred in children with incomplete vaccination. Though 11 of these involved children too young to have completed the series, nine cases were due to significant delays or parent refusal of the initial or subsequent doses. Second, timeliness prevents further delays in other vaccinations, which could otherwise set in motion a domino effect. Failure to obtain vaccinations on schedule increases the risk of failing to ever achieve full immunization (Guerra 2007). While UTD rates are high, children rarely receive all recommended vaccinations in a timely manner (Luman et al. 2005a).

To better improve the prospects of preventing future vaccine-preventable disease outbreaks, it is necessary to both increase UTD coverage and decrease underimmunization. Though simply put, the matter is quite complicated. Besides merely looking at costs of vaccination, other obstacles to increasing UTD and decreasing underimmunization rates must be studied. Analyzing these barriers is critical for public health policies and campaigns to be effective. Thus, the purpose of this study is twofold. First, the primary aim is to identify determinants of immunization outcomes that consistently prove to be risk factors over time. A secondary aim is to assess any changes in the effects of these variables on outcomes; in particular, it would be helpful to determine if any disparities between certain groups have intensified or been bridged.

LITERATURE REVIEW

An extensive body of literature argues family structure is highly influential in determining immunization outcomes. Children of single mothers and larger families tend to be at greatest risk for non-UTD status and underimmunization (Bobo et al. 1993; Bardenheier et al. 2004; Dombkowski et al. 2004). Moreover, higher order children are significantly more likely to receive delayed vaccinations than first-born children; they are also at heightened risk if the child lives in a household with multiple children or if he or she has an older sibling who was immunized late (Schaffer and Szilagyi 1995; Brenner et al. 2001; Kim et al. 2007; Feemster et al. 2009).

The conceptual framework behind these findings is rooted in the tradeoffs between childcare and family organization. Evidence suggests that as family size grows there is increasing need for family organization as well as less worry for second-born and subsequent children. In keeping with this mechanism, children with two parents and those raised in the presence of grandmothers are at significantly lower risks of having delays. This is partly due to a mix of stronger social support and decreased family organization burdens on the mother. (Brenner et al. 2001; Dombkowski et al. 2004). Moreover, budget constraints force caretakers to allocate a limited number of resources devoted to children. For primarily this reason, employed mothers are more often linked to better child immunization outcomes (Brenner et al. 2001).

Related to this framework is the caretakers' ability to overcome the financial burdens vaccinations present. Empirical evidence suggests out-of-pocket (OOP) costs constitute a barrier to obtaining immunizations. Efforts have been made to reduce OOP costs by the Vaccines for Children (VFC) program. This public volume-purchasing program provides vaccine antigens free of charge to select medical providers but does not cover other immunization related expenses such as fees for vaccine administration and well-child examinations. By also limiting allowable administration fees to maximums set by the CDC, the VFC helps to decrease OOP costs. While such efforts are reasonable, immunization rates between children receiving vaccines from VFC and non-VFC providers are very similar (Taylor et al. 1997). Nonetheless, efforts aimed at reducing parents' financial burdens are vital because complete elimination of OOP costs is estimated to increase UTD coverage by 7% in Georgia (Molinari et al. 2007). For similar reasons, the American Academy of Pediatrics recommends policies that reimburse for physician work, vaccine-related supplies, and professional liabilities and thereby improve coverage (Committee 2003).

Moreover, parental attitudes are argued to be critical intangibles in the prediction of children's immunization. Partly because parental attitudes are tough to capture empirically, they do not explain outcomes outright but still factor heavily in the decision-making process. When applying social learning theories to the matter, investigators found children of mothers who do not believe in the importance of timely vaccination and those of parents who believe in the safety of obtaining multiple immunizations in one visit were less likely to be immunized (Strobino et al. 1996). The same holds true for children of parents who are uncertain in their capabilities of obtaining all recommended vaccinations (Brenner et al. 2001). Additionally, uncertainty in the efficacy of vaccines tends to weakly predict outcomes but nevertheless remains a readily identified concern amongst parents (Prislin et al. 1998; Taylor et al. 2002b.). Parental attitudes, beliefs, and behaviors indicative of vaccine safety concerns contribute significantly to underimmunization (Gust et al. 2004).

Attitudes and beliefs regarding natural immunity and perceived barriers are also of great interest. Preconceived notions of natural immunity, especially amongst healthy children, tend to lower immunization rates (Prislin et al. 1998). Perceived barriers, such as a sense of inconvenience in obtaining vaccines and confusing vaccination schedules, are statistically associated with an increased risk for underimmunization (Brenner et al. 2001). However, only a small proportion of parents identified such barriers, which help explain less than 10% of underimmunization observed in pediatric office settings (Taylor et al. 2002b). Nonetheless, all of these findings suggest parental attitudes, perceptions, and notions regarding immunization play an important role in influencing outcomes.

The key to the effects of parental attitudes is mediated by how their perceptions affect their sense of control. Its role is highlighted in cases of distrust between parents and medical professionals. Among children whose doctor-parent relationships are strained, immunization rates tend to be lower. A parent's heightened sense of control is positively associated with outcomes but distrust is argued to undermine favorable decisions, and thereby erode immunization rates (Prislin et al. 1998).

Along with attitudes, education of caretakers plays an integral part in influencing outcomes since obtaining child vaccinations is based on informed decision-making. In two of four medically underserved areas, mother's education level was found to be strongly positively associated with UTD status at three months of age (Bardenheier et al. 2004). Additionally, according to National Health Interview Survey (NHIS) Immunization Supplement 1992-1996 pooled data, children of parents with education beyond high school exhibit significantly lower chances of being underimmunized for the 4:3:1 series (Domkowski et al. 2004). In general, higher maternal education is linked with favorable child immunization outcomes (Bobo et al. 1993; Luman et al. 2005b; Kim et al. 2007; Feemster et al. 2009).

Immunization rates among children of better-educated parents tend to be higher because they are better informed of the safety of vaccines and are less distrustful of professionals. However, better-educated caretakers tend to refuse vaccinations more often due to medically unjustified contraindications, such as a common cold; this is most probably due to being thoroughly informed of possibly sensationalized side effects (Prislin et al. 1998). Thus, education plays a primarily positive role but when influencing beliefs about contraindications, it may bring about a reverse effect.

Decision-making is also dependent on maintaining an exclusive relationship with vaccine providers. Children of parents who do so generally experience favorable outcomes (Luman et al. 2005b). Children with multiple vaccine providers are much more likely to experience a lengthy 4:3:1 series delay; they are also one and a half times as likely to not receive the DTP4 and MMR1 doses (Dombkowski et al. 2004). While this is partly due to information transfer and mismanagement problems of medical records, such evidence also implicates the importance of the role medical providers play in children's immunizations.

Previous studies show private practitioner attitudes and perceptions of vaccines bear significant weight on outcomes as well. In particular, children are more likely to be UTD if seen by providers who deem vaccinations profitable; by placing caps on vaccine administration fees, the VFC is argued to effectively weaken the profit-motive that might otherwise raise immunization coverage rates above their non-VFC counterparts (Taylor et al. 1997). Providers who accept fewer unjustified medical contraindications are strongly associated with favorable outcomes as well (Taylor et al. 1997; Taylor et al. 2002a). Evidently, provider practices and preferences play an important role in mediating vaccination outcomes (Lieu et al. 1996).

The health care setting in which vaccination providers work is linked to outcomes as well. Children receiving vaccinations from public providers are more likely to be underimmunized (Luman et al. 2005b). Moreover, public health and university/hospital-based clinics are more likely to have delayed initiation of immunization series compared to private pediatricians' offices (Feemster et al. 2009).

In addition to the influences of parents and providers, Steyer et al. 2004 found race and region of residence to exert some effect on immunization status as well. Their research shows there is no difference in delays between children living in metropolitan and rural areas. Moreover, minority children in rural areas are no more likely to experience delays than their metropolitan counterparts. However, newly introduced recommendations are less likely to be adhered to in rural areas, though such discrepancies generally disappear two years after the introduction is made (Steyer et al. 2004).

Other findings show that Hispanic children are less likely to experience underimmunization, which aligns well with the Hispanic epidemiological paradox. It refers to the consistent finding that Hispanics in the United States tend to have better health outcomes than what would be expected according to socioeconomic predictors. The causes of this phenomenon are poorly understood but one possible explanation is that Hispanic culture emphasizes strong family values and strong protection of their children (Marsiglia 1992). This may explain better outcomes among Hispanic children's immunizations (Kim et al. 2007).

Overall, the existing body of literature suggests there are identifiable characteristics that place children at greater risk of being non-UTD or underimmunized. To date, however, little emphasis has been placed on assessing changes these risk factors have had over time. Observing sizeable changes, whether they are positive or negative, may help policymakers determine which risk factors or population groups to target going forward. Thus, this study aims not only to identify consistent risk factors but also to determine whether the United States has achieved greater parity among socioeconomic and demographic strata.

DATA AND METHODS

This study uses yearly data from the 1999-2008 National Immunization Survey (NIS). The CDC publicly issues the annual NIS, a two-tiered survey that collects yearly answers from households and health care providers for children between the ages of 19-35 months since 1995. Households with age-eligible children are first contacted randomly via telephone. Respondents provide information regarding socioeconomic and demographic characteristics and immunization information. After consent is obtained from household respondents, a survey is mailed out to children's vaccination providers to validate immunization information.

Building on previous literature, dependent variables were constructed for the last components of two immunization series: the fourth dose for diptheria-tetanus-pertussis (DTP4) and the first for measles-mumps-rubella (MMR1). The dependent variables capture the presence or absence of delay in receipt of the aforementioned doses. Using recommendations from the CDC's *Recommended Immunization Schedule for Persons Aged 0 Through 6 Years*, which is annually updated, delays were considered present if the child's age at receipt of vaccination exceeded the maximum age at which the dosage of interest is recommended. The recommended ages for DTP4 and MMR1 remained unchanged between 1999–2008 at 15–18 months and 12–15 months respectively. Thus, for example, children who received DTP4 after 18 months of age were considered delayed for DTP4.

Each probit model examined the relationship between immunization outcomes and household characteristics, family demographics, and relevant medical care information. Based on findings from previous studies, variables were chosen from 1999-2008 NIS data. Those that were available in all years were included to make the most comprehensive model possible. These include child's race-ethnicity (*white*, black, Hispanic, other), first-born status of child, number of children in the household under 18 years of age (*one*, two or three, four or more), mother's age (≤19 years, 20-29, *30+*) and education (< 12 years, high school or some college, *college graduate*), income-to-poverty ratio (≤ 50% of FPL, 50%-300% of FPL, *> 300% of FPL*) provider's facility type (*private*, public including WIC and military, hospital, mixed) and how many of vaccine providers order vaccines from the VFC program (*all*, some, none). The italicized variables represent reference groups that were assigned based on largest size and greatest homogeneity. Probit regressions were estimated separately for each year.

After dropping missing data, the sample size across the ten data waves varied between 12,389 (2007) and 17,888 (2004). If the respondent indicated an unknown facility type, the specific observation was dropped. All dataset treatments, modifications, and statistical analyses were conducted using SAS 9.1.3.

RESULTS

As shown in Table 1, the percentage of children in the sample of provider records with delay in receipt of MMR vaccine decreased progressively from 17.5% in 1999 to 11.8% in 2008. The proportion of children with delay in receipt of DTP vaccine ranged from 16.1% and 17.8% but did not exhibit a clear trend over time. Across the years, a representative family in the sample identified itself as non-Hispanic white (58.6%- 62.7%), tended to have 2–3 children (59.6%-63.7%) under the age of 18 years in the household, and had mostly first-borns (52%-59.9%). Most mothers were married (73.2%-78.4%) and were over 30 years of age (53.5%-66.5%). With respect to education, most mothers graduated high school or had some college (39.7%-52.0%) though in some years, they are equally likely to have a college degree (35.5%-49.9%). Additionally, in terms of provider characteristics, most respondents indicated that all of their vaccine providers participated in the VFC program (74.1%-82.3%) and that most vaccines were received at private medical facilities (62.8%-69.9%).

Tables 2 and 3 present marginal effects derived from probit analyses in each year for MMR and DTP vaccine delays. Certain groups were consistently significant predictors in both models. First-borns and married mothers were significantly linked with favorable outcomes for at least nine years in both models. Compared to higher order children, first-borns were 1.8–7.0 and 2.2–5.2 percentage points less likely to have delayed MMR and DTP vaccines, respectively. Compared to single mothers (non-married, separated, divorced or widowed), married mothers were 2.1–4.5 and 2.7–4.6 percentage points less likely to have delays for the two vaccines.

Also consistently significant across the years, though influencing outcomes negatively, were family size of four or more children and the mother's age group of between 20–29 years. Compared to children in households with one child, children in those with four or more children were 5.7–10.0 and 4.5–9.0 percentage points more likely to have delayed MMR and DTP vaccines, respectively. Children of mothers between 20-29 years of age were 1.3–2.8 and 1.6–2.8 percentage points more likely to have delayed receipt of the two vaccines. The effect of first-born status shows a downward trend over time, whereas the effect of four or more children appears to have become stronger over the years.

A household with two or three children was also statistically significant; though only significant in five years for MMR delay, its effects were significant in nine years for DTP delay and ranged between 1.8–4.1 percentage points. The youngest age group of mothers was not statistically significant in predicting outcomes in either model.

With respect to mothers with a college degree, children of those having high school or some college background were more likely to have delayed DTP immunization across all years.

This group was also a significant predictor in seven of ten years for MMR1 delay. Having less than 12 years of education was a significant risk factor as compared to college educated mothers in four years for MMR1 delay and six for DTP4 delay.

A noteworthy contrasting result between the MMR and DTP delay models concerns race and ethnicity. While Hispanic children yielded negative marginal effects for MMR, meaning they are less likely to be underimmunized, this group was not a significant predictor of DTP delay in any year. Similarly, non-Hispanic black children were at significantly higher risk for DTP delay in all years but not MMR delay.

Provider facility type proved to be a strong predictor in many years. Compared to receiving vaccinations in private medical settings, receipt of vaccinations at public facilities, WIC clinics, or military settings was a risk factor in four years for MMR delay and five for DTP delay. On the other hand, providers in hospital settings were significantly linked with timely immunization in eight or more years for both models. Hospital settings rendered children 1.8–4.2 and 2.0–5.6 percentage points less likely to experience delays in receiving MMR and DTP vaccines. Children receiving vaccinations from a mixed sample of facility types were at greater risk of being underimmunized in six years for MMR but only two for DTP4.

Additionally, VFC participation and having vaccines ordered from the state or local health department was somewhat useful in predicting delay outcomes. Compared to having all providers participating in the VFC, children not vaccinated by VFC-participating providers were at significantly higher risk for MMR1 delay in six years. However, this was not the case in any year for DTP4 delay. Having some but not all providers ordering from the VFC was not a strong predictor in either model.

DISCUSSION

Probit regressions for both models revealed several key findings. First, children of married mothers and those that are first-borns are at significantly lower risk of being underimmunized for DTP4 and MMR. A greater number of children in the household tends to undermine timely vaccination as well. These findings align well with the existing literature and proposed models. As previously suggested, mothers face tradeoffs between family organization and child-care and thus, children are better off if they are taken care of by more than one parent and if they are the first-born within the family. Subsequent children are thus at greater risk of being underimmunized. Single mothers are argued to also have less social support resources (i.e., additional caretaker in the household) that could otherwise help ease stress.

While such a mechanism is likely to mediate effects, the marginal effects of first-born status decreased progressively throughout the decade. This suggests that policies and the vigilance of providers have achieved greater parity in underimmunization between first-born and higher order children. At the same time, however, the marginal effect of having four or more children in the household intensified over the ten-year period. A valid mechanism accounting for this phenomenon remains to be identified. Regardless, future studies and policies should heed this development in their efforts.

Second, education continues to play a significant role in mediating outcomes. Mothers with less education, namely those with high school or some college, are more likely to obtain untimely vaccinations for their children. On a related note, younger mothers were also more likely to have their children be underimmunized. Linking younger mothers and less education with untimely vaccination is reasonable since obtaining vaccinations is heavily dependent on informed decision-making and experience. It can be argued that older mothers are also those who obtained college degrees and are overall better informed of the benefits of vaccines. Thus, future immunization campaigns should keep less educated and younger mothers at the forefront of their efforts.

Other risk factors identified came from within the race-ethnicity groups. After controlling for socioeconomic status, maternal education and age, and family size, Hispanics tended to be at lower risk for MMR delay. However, this group yielded insignificant results for DTP4 delay. This might suggest Hispanic children are at lower risk of underimmunization for earlier vaccinations but are at no less risk for delay in later immunizations than non-Hispanic white children. A competing explanation, which is consistent with the Hispanic paradox, is that Hispanic culture highlights childcare.

On the other hand, non-Hispanic black children tended to be at higher risk of DTP4 delay across all years as compared to white children. These two groups, however, were on an equal footing with respect to risk of MMR delay. It is possible that black children receive earlier vaccinations on a timely basis but over time, immunizations in later stages of a series are not. Accordingly, black children are at higher risk of untimely DTP4 vaccination since the dose in this study was the fourth in the DTP series, whereas MMR consists of only one.

A striking finding regarding race-ethnicity concerns the households that identified themselves as non-Hispanic other. For MMR1 delay, the marginal effect of this group was mostly negative and significant in four years. On the contrary, its marginal effect on the probability of DTP delay was mostly positive and also significant in four years. Contrasting influences make interpretation all the more difficult. Definitive conclusions could probably be made with further research and larger sample size.

The lack of consistent significance of income-to-poverty variables was unexpected. Compared to households above 300% of the FPL, children in households between 50% and 300% of the FPL were at higher risk of DTP4 delay in 1999, 2002, 2005, and 2007 and MMR1 delay in 2003. Those under 50% of the FPL were at significantly higher risk of DTP4 delay in 1999 and MMR1 in 2004. Otherwise, income-to-poverty ratios were not strong predictors of outcomes. While this might suggest a lack of relationship, the lack of significance can most probably be attributed to small sample size. Otherwise, previous studies show family income and poverty status strongly mediate effects (Bardenheier et al. 2004).

With respect to differences in risk due to providers, VFC participation was found to affect outcomes, though primarily for MMR immunizations. Since caretakers are likely to face lower out-of-pocket (OOP) costs when receiving vaccines from VFC-participating providers, insurance coverage notwithstanding, it is reasonable their children are at lower risk of untimely vaccination. However, not having any medical providers order vaccines from state or local health departments was a risk factor for only MMR delay but not DTP4 delay. This difference may be attributed to the differences in costs for providing both vaccines. According to the CDC Vaccine Price List (updated April 6, 2010), the highest private sector cost of a DTP vaccine is $23.757 whereas the private cost of MMR vaccine is $128.90. Compared to DTP vaccine, the notably higher costs of MMR vaccine are likely to dissuade caretakers more if they are forced to pay the private market price. However, such conclusions can only be definitively drawn if OOP costs are factored into the regressions.

Additionally, providers' practice settings influenced underimmunization to a considerable degree. Compared to private practices, hospital settings were found to place children at significantly lower risk of underimmunization, a finding inconsistent with Feemster et al. 2009.

The results from this may arguably be attributed to economies of scale. Small private practices, namely solo practices or those with two practitioners, were found to place children at over twice the odds of being non-UTD for basic immunization series (Kahane et al. 2000). Hospitals, on the other hand, have larger staff sizes and access to greater resources and may thus be able to better manage underimmunization. However, definitive conclusions can only be made with research targeted at hospitals and private settings. Additionally, mixed facility type was found to be a risk factor, which is consistent with previous literature (Luman et al. 2005b). Not having a usual provider places children at higher risk of non-UTD status for MMR (Dombkowski et al. 2004). Children receiving vaccinations from mixed facilities are probably at higher risk due to problems with accurate record keeping, though this mechanism remains to be validated with strong empirical evidence. Regardless, caretakers resorting to mixed facility types should be targeted in future policy efforts.

CONCLUSIONS AND IMPLICATIONS

From probit analyses, risk factors for delay in receipt of MMR and DTP4 vaccinations were identified. In particular, households with mothers between the ages of 20-29 and family size with four or more children exerted positive marginal effects on delay. Also, receiving vaccines from public or mixed facility types and not having any providers order vaccines from the VFC program exerted similar effects. Factors that reduced these risks were first-born status, smaller family size, married mothers, Hispanic origin, and receiving vaccines in hospital settings. Overall, these findings correlate well with the existing literature.

The main contribution of this study is its focus on changes in marginal effects across time. While most effects did not follow suggestive trends, the effects of first-born status and family size exhibited noteworthy movements that deserve mention. The influence of first-born status diminished whereas that of larger family size intensified over the decade. This suggests that policies and efforts on the part of providers have been successful in bridging the disparities between first-born and higher order children. However, families with four or more children became progressively at higher risk. Efforts that increase vigilance of timely vaccination for parents with multiple children may be effective going forward.

The primary advantage of this study lies in its focus on socioeconomic, demographic, and provider characteristics of a nationally representative sample across a decade. Many have identified risk factors amongst citywide and state populations but relatively few have studied nationally representative data. Additionally, most studies focused on identifying risk factors based on data from one year. However, certain groups may exert significant influence on outcomes within a given year due to the concurrent environment. For example, the effects of low income may heighten affordability issues more extensively in times of poor economic performance. In such instances, forgoing vaccination may be more desirable. Though a consistently significant relationship did not exist between income-to-poverty ratios and vaccination delay outcomes, such an example merely highlights the issue at hand. Studies focused on data from one year only identify the main factors affecting outcomes in that timeframe. However, such findings are not representative of systemic risk factors that policymakers should focus on continually. From this study, policymakers will be able to determine which factors undermine outcomes persistently.

The drawbacks of this study include the use of secondary data of the NIS. In particular, the data was limited to questions asked by the survey team and answers provided by the respondents. We also could not factor into the model the effects of medical conditions. For example, prematurity can influence timeliness that would otherwise be considered unfavorable. Our models also did not include variables capturing provider and parental attitudes and out-of-pocket costs. Pooling data from two-year periods and instead constructing five probit models could improve the study.

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APPENDIX

Table 1. Summary Statistics: frequencies by year.

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Dependent Variables											
MMR delay		0.175 (0.380)	0.160 (0.367)	0.151 (0.358)	0.152 (0.359)	0.140 (0.347)	0.135 (0.342)	0.142 (0.349)	0.129 (0.336)	0.124 (0.329)	0.118 (0.323)
DTP4 delay		0.171 (0.376)	0.169 (0.375)	0.171 (0.377)	0.178 (0.383)	0.188 (0.391)	0.161 (0.368)	0.174 (0.379)	0.168 (0.374)	0.166 (0.372)	0.170 (0.376)
Child Demographics											
First-born		0.573 (0.495)	0.576 (0.494)	0.581 (0.493)	0.597 (0.490)	0.588 (0.492)	0.599 (0.490)	0.528 (0.499)	0.539 (0.498)	0.520 (0.500)	0.526 (0.499)
Number of children	*One*	0.295 (0.456)	0.291 (0.454)	0.290 (0.454)	0.291 (0.454)	0.277 (0.447)	0.276 (0.447)	0.270 (0.444)	0.249 (0.432)	0.248 (0.432)	0.238 (0.426)
	Two or three	0.596 (0.491)	0.602 (0.489)	0.606 (0.489)	0.601 (0.490)	0.615 (0.487)	0.613 (0.487)	0.612 (0.487)	0.632 (0.482)	0.630 (0.483)	0.637 (0.481)
	Four	0.109 (0.311)	0.107 (0.309)	0.104 (0.305)	0.108 (0.310)	0.109 (0.311)	0.111 (0.314)	0.118 (0.322)	0.119 (0.324)	0.121 (0.327)	0.126 (0.331)
Race-Ethnicity	*White*	0.627 (0.483)	0.613 (0.487)	0.615 (0.487)	0.606 (0.489)	0.590 (0.492)	0.597 (0.491)	0.604 (0.489)	0.586 (0.493)	0.627 (0.484)	0.626 (0.484)
	Hispanic	0.168 (0.374)	0.188 (0.391)	0.192 (0.394)	0.186 (0.389)	0.205 (0.403)	0.203 (0.403)	0.203 (0.403)	0.224 (0.417)	0.197 (0.397)	0.182 (0.386)
	Black	0.145 (0.352)	0.145 (0.353)	0.139 (0.346)	0.121 (0.326)	0.118 (0.323)	0.110 (0.313)	0.104 (0.305)	0.099 (0.299)	0.083 (0.276)	0.096 (0.294)
	Other	0.059 (0.236)	0.053 (0.224)	0.054 (0.225)	0.088 (0.283)	0.087 (0.283)	0.090 (0.286)	0.088 (0.284)	0.092 (0.289)	0.094 (0.292)	0.096 (0.295)
Mother's Age	≤19 years	0.031 (0.173)	0.029 (0.168)	0.029 (0.168)	0.024 (0.152)	0.020 (0.141)	0.021 (0.142)	0.019 (0.136)	0.018 (0.134)	0.018 (0.131)	0.016 (0.127)
	20-29	0.434 (0.496)	0.434 (0.496)	0.416 (0.493)	0.389 (0.488)	0.398 (0.489)	0.390 (0.488)	0.368 (0.482)	0.354 (0.478)	0.334 (0.472)	0.319 (0.466)
	30+	0.535 (0.499)	0.537 (0.499)	0.555 (0.497)	0.587 (0.492)	0.582 (0.493)	0.590 (0.492)	0.613 (0.487)	0.627 (0.483)	0.648 (0.478)	0.665 (0.472)
Mother's Education	< 12 years	0.124 (0.330)	0.124 (0.329)	0.120 (0.326)	0.112 (0.315)	0.124 (0.329)	0.118 (0.323)	0.104 (0.305)	2.992 (1.071)	0.109 (0.311)	0.099 (0.299)
	12 years or some college	0.520 (0.500)	0.504 (0.500)	0.464 (0.499)	0.456 (0.498)	0.442 (0.497)	0.433 (0.496)	0.397 (0.489)	0.430 (0.495)	0.452 (0.498)	0.443 (0.497)
	College graduate	0.355 (0.479)	0.372 (0.483)	0.416 (0.493)	0.433 (0.495)	0.435 (0.496)	0.449 (0.497)	0.499 (0.500)	2.992 (1.071)	0.439 (0.496)	0.458 (0.498)
Marital Status	*Married*	0.742 (0.437)	0.732 (0.443)	0.745 (0.436)	0.756 (0.430)	0.749 (0.433)	0.762 (0.426)	0.762 (0.426)	0.768 (0.422)	0.784 (0.411)	0.779 (0.415)
	Single	0.258 (0.437)	0.268 (0.443)	0.255 (0.436)	0.244 (0.430)	0.251 (0.433)	1.238 (0.426)	0.238 (0.426)	0.232 (0.422)	0.216 (0.411)	0.221 (0.415)
Income-to-Poverty Ratio	≤ 0.5	0.176 (0.381)	0.180 (0.384)	0.175 (0.380)	0.161 (0.367)	0.166 (0.372)	0.158 (0.365)	0.144 (0.351)	0.152 (0.359)	0.137 (0.344)	0.089 (0.285)
	0.5 – 3.0	0.484 (0.500)	0.498 (0.500)	0.469 (0.499)	0.449 (0.497)	0.452 (0.498)	0.449 (0.497)	0.433 (0.496)	0.426 (0.495)	0.428 (0.495)	0.453 (0.498)
	> 3.0	0.340 (0.474)	0.323 (0.468)	0.356 (0.479)	0.391 (0.488)	0.382 (0.486)	0.393 (0.488)	0.423 (0.494)	0.422 (0.494)	0.435 (0.496)	0.458 (0.498)
Provider Characteristics											
Provider Facility Type	*Private*	0.628 (0.483)	0.630 (0.483)	0.646 (0.478)	0.672 (0.469)	0.670 (0.470)	0.669 (0.471)	0.699 (0.459)	0.684 (0.465)	0.682 (0.466)	0.663 (0.473)
	Public (WIC, military)	0.207 (0.405)	0.195 (0.396)	0.181 (0.385)	0.159 (0.366)	0.155 (0.362)	0.147 (0.354)	0.134 (0.341)	0.144 (0.352)	0.133 (0.339)	0.131 (0.337)
	Hospital	0.082 (0.274)	0.089 (0.285)	0.088 (0.284)	0.096 (0.294)	0.092 (0.289)	0.096 (0.295)	0.095 (0.293)	0.095 (0.293)	0.096 (0.295)	0.097 (0.296)
	Mixed	0.083 (0.276)	0.086 (0.280)	0.085 (0.279)	0.073 (0.259)	0.083 (0.276)	0.088 (0.284)	0.072 (0.259)	0.077 (0.266)	0.089 (0.284)	0.109 (0.311)
VFC Participating Providers	*All*	0.779 (0.415)	0.792 (0.406)	0.801 (0.399)	0.806 (0.395)	0.800 (0.400)	0.802 (0.398)	0.823 (0.382)	0.776 (0.417)	0.741 (0.438)	0.784 (0.412)
	Some	0.044 (0.206)	0.044 (0.205)	0.039 (0.193)	0.037 (0.189)	0.050 (0.218)	0.044 (0.204)	0.034 (0.180)	0.042 (0.201)	0.054 (0.226)	0.080 (0.271)
	None	0.091 (0.287)	0.090 (0.287)	0.092 (0.290)	0.093 (0.290)	0.089 (0.285)	0.093 (0.290)	0.090 (0.286)	0.131 (0.338)	0.130 (0.336)	0.136 (0.343)
N (sample size)		16383	15951	16460	16048	17412	17888	13724	14185	12389	12875

Frequencies shown with standard deviations in parentheses. Reference groups indicated in italics.

Table 2. Probit regression results for delay in receipt of first mumps-measles-rubella (MMR1) vaccine, 1999-2008.

	1999		2000		2001		2002		2003		2004		2005		2006		2007		2008	
First-born	-0.0455	***	-0.0701	***	-0.0536	***	-0.0406	***	-0.0370	***	-0.0444	***	-0.0294	***	-0.0297	**	-0.0245	***	-0.0184	
Number of children in household																				
Two or three	0.0295	***	0.0080		0.0197	**	0.0129		0.0074		0.0061		0.0233	***	0.0212	**	0.0082		0.0251	**
Four or more	0.0895	***	0.0467	***	0.0586	***	0.0693	***	0.0624	***	0.0497	***	0.0709	***	0.0685	***	0.0454	***	0.0847	
Race-Ethnicity																				
Hispanic	-0.0427	***	-0.0392		-0.0479	***	-0.0511	***	-0.0369	***	-0.0370	***	-0.0516	***	-0.0471	***	-0.0284	***	-0.0423	
Black	-0.0129		0.0140	***	-0.0154		-0.0119		0.0127		-0.0072		-0.0325	***	-0.0142		0.0106		-0.0033	
Other	-0.0348	***	-0.0408	***	-0.0267	**	-0.0034		-0.0027		-0.0091		-0.0198	*	-0.0157		-0.0123		0.0056	
Mother's Age																				
≤19 years	0.0070		0.0063		-0.0003		0.0230		0.0156		0.0182		-0.0120		0.0050		0.0085		0.0025	
20-29	0.0160		0.0283	***	0.0129	**	0.0259	***	0.0161	***	0.0183	***	0.0183	***	0.0233	***	0.0150	*	0.0159	**
Mother's Education																				
< 12 years	0.0144		0.0268	**	0.0064		0.0261	**	0.0294	***	-0.0051		0.0277	**	-0.0012		0.0213		0.0136	
12 years or some college	0.0206	***	0.0186	***	0.0115	*	0.0145	**	0.0160	**	0.0155	**	0.0229	***	0.0035		0.0127		0.0102	
Mother's Marital Status																				
Married	-0.0330	***	-0.0254	***	-0.0451	***	-0.0326		-0.0086		-0.0309	***	-0.0207	**	-0.0268	***	-0.0254	***	-0.0374	
Income-to-Poverty Ratio																				
≤ 0.5	0.0209		0.0005		-0.0029		0.0149		-0.0069		0.0138		0.0060		0.0053		0.0040		0.0096	
0.5 – 3.0	0.0156		0.0105		0.0099		0.0184	**	0.0104		0.0033		0.0254	***	0.0029		0.0147	*	0.0074	
Provider Facility Type																				
Public, WIC, Military	0.0003		0.0119		-0.0127		-0.0207	**	0.0134	*	0.0072		0.0007		-0.0051		0.0067		0.0185	**
Hospital	-0.0232	**	-0.0380	***	-0.0248	**	-0.0176	*	-0.0194	**	-0.0368	***	-0.0419	***	-0.0256	***	-0.0213	*	-0.0099	
Mixed	0.0238	**	0.0604	***	0.0481	***	0.0220	*	0.0309	***	0.0184	*	0.0141		0.0258	**	0.0209		0.0039	
Number of VFC Participating Providers																				
Some	0.0164		-0.0066		0.0063		0.0223		0.0274	**	0.0206		0.0046		-0.0388		-0.0088		-0.0003	
None	0.0028		0.0207	**	0.0099	**	0.0272	***	0.0293	***	0.0047		0.0195	*	0.0051		0.0421		0.0261	**
N (sample size)	16383		15951		16460		16048		17412		17888		13724		14185		12389		12875	

Presented values are marginal effects.

The symbols ***, **, and * represent statistical significance at $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively.

Source: National Immunization Survey, 1999-2008

Table 3. Probit regression results for delay in receipt of fourth diphtheria-tetanus-pertussis (DTP4) vaccine, 1999-2008.

	1999		2000		2001		2002		2003		2004		2005		2006		2007		2008	
First-born	-0.0305	***	-0.0465	***	-0.0516	***	-0.0399	***	-0.0414	***	-0.0509	***	-0.0428	***	-0.0445	***	-0.0227		-0.0224	***
Number of children in household																				
Two or three	0.0375	***	0.0185	*	0.0313	***	0.0326	***	0.0209	**	0.0144		0.0391	***	0.0257	***	0.0405	***	0.0406	***
Four or more	0.0875	***	0.0574	***	0.0696	***	0.0703	***	0.0982	***	0.0753	***	0.0962	***	0.0976	***	0.0831	***	0.1000	***
Race-Ethnicity																				
Hispanic	0.0146		0.0170		0.0029		-0.0041		0.0135		0.0034		-0.0098		0.0069		0.0039		-0.0027	
Black	0.0413		0.0275	***	0.0456	***	0.0334	***	0.0352	***	0.0378	***	0.0516	***	0.0330	***	0.0547	***	0.0306	**
Other	0.0263	**	-0.0038		0.0158		0.0012		0.0348	***	0.0119		0.0202	*	0.0175		0.0326		0.0214	
Mother's Age																				
≤19 years	-0.0094		0.0114		-0.0125		-0.0110		0.0570		0.0057		-0.0069		-0.0156		-0.0061		-0.0035	
20-29	0.0081		0.0211	***	0.0190	***	0.0191	***	0.0203	***	0.0164	**	0.0282		0.0189	***	0.0244	***	0.0283	***
Mother's Education																				
< 12 years	0.0304		0.0149		0.0100		0.0347	***	0.0271	**	0.0121		0.0425	***	-0.0064		0.0356		0.0264	
12 years or some college	0.0133	*	0.0144	**	0.0149		0.0229	***	0.0243	***	0.0327	***	0.0267	***	0.0129	*	0.0324	***	0.0340	***
Mother's Marital Status																				
Married	-0.0328	***	-0.0412	***	-0.0463	***	-0.0362	***	-0.0461	***	-0.0361	***	-0.0334	***	-0.0367	***	-0.0271		-0.0447	***
Income-to-Poverty Ratio																				
≤ 0.5	-0.0037		0.0057		-0.0117		0.0041		0.0028		0.0252		0.0019		0.0157		0.0156		-0.0167	
0.5 – 3.0	0.0037		0.0082		-0.0033		0.0101		0.0148		0.0059		0.0027		0.0115		0.0006		-0.0024	
Provider Facility Type																				
Public, WIC, Military	-0.0576	***	-0.0391	***	-0.0294	***	-0.0212	**	-0.0022		-0.0026		-0.0039		-0.0169	*	-0.0019		0.0182	*
Hospital	-0.0557	***	-0.0478	***	-0.0219	**	-0.0360	***	-0.0170		-0.0199	**	-0.0167		-0.0280	**	-0.0430	***	-0.0258	**
Mixed	-0.0190		0.0142		0.0153		0.0044		0.0079		0.0185		0.0209		0.0044		0.0125		0.0075	
Number of VFC Participating Providers																				
Some	0.0041		0.0028		0.0049		0.0495		0.0246		-0.0058		-0.0035		0.0054		-0.0142		-0.0046	
None	0.0229		0.0035		0.0082		0.0250		-0.0028		0.0081		0.0037		-0.0002		0.0047		0.0010	
N (sample size)	16383		15951		16460		16048		17412		17888		13724		14185		12389		12875	

Presented values are marginal effects.

The symbols ***, **, and * represent statistical significance at $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively.

Source: National Immunization Survey, 1999-2008