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POLICY RESEARCH DIVISION

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ABSTRACT

Research conducted in Africa has demonstrated consistently that parental poverty and low educational attainment adversely affect child survival. Research conducted elsewhere has demonstrated that low-cost vaccines against preventable diseases reduce childhood mortality. Therefore, the extension of vaccination to impoverished populations is widely assumed to diminish equity effects. Recent evidence that childhood mortality is increasing in many countries where vaccination programs are active challenges this assumption. This paper marshals data from accurate and complete immunization records and survival histories for 18,368 children younger than five in a rural northern Ghanaian population that is generally impoverished, but where family wealth and parental educational differentials exist nonetheless. Time-conditional Weibull hazard models are estimated to test the hypothesis that childhood immunization offsets the detrimental effects of poverty and low educational attainment. Findings show that the adverse effects of poverty disappear and that the effects of educational attainment are reduced in survival models that control for immunization status. This finding lends empirical support to policies that promote immunization as a strategic component of poverty-reduction programs.

Research throughout Africa has shown that parental poverty and low educational attainment are adversely associated with the survival of children (Muhuri 1995; Montgomery et al. 2000; Filmer and Pritchett 2001; Gwatkin 2002a; Bawah and Zuberi 2005; Debpuur et al. 2005; Kahn et al. 2005; Nathan et al. 2005). Extensive scientific evidence also demonstrates that low-cost vaccines are effective in reducing childhood mortality (World Bank 1993; Nyarko et al. 2001; Victora et al. 2003; GAVI 2005; Levine et al. 2005; United Nations 2006). Therefore, the adverse child-survival effects of poverty and low parental educational are widely assumed to be offset by the promotion of comprehensive childhood immunization (World Bank 1993; Sachs and MacArthur 2005), and immunization has become a critical component of policies that aim to address health inequity (Gwatkin et al. 2005). Nonetheless, an examination of the impact of immunization on the association between poverty and child survival should be appraised directly. Health conditions, particularly for children, are worsening throughout sub-Saharan Africa despite the widespread promotion of immunization in the region (Timaeus 1997a, 1997b, and 1999; Ahmad et al. 2000; Black et al. 2003; Hill 1993; United Nations 2005a and 2005b; World Bank 2005). This finding challenges the assumption that immunization offsets the effects of poverty. Extrapolations of trends suggest that the Millennium Development Goals (MDGs) for child survival are not being achieved in the region (Sahn and Stifel 2003). Moreover, assessing the precise relationship between immunization and poverty alleviation is constrained by the difficulty in marshaling accurate and complete immunization data in conjunction with longitudinal survival observation of large cohorts of children (Fine 2005; Aaby and Jensen 2005. For this reason, evidence from aggregate data that mortality declines are stagnating cannot be linked with information on immunization coverage. The role of immunization coverage in the stagnation of trends is unknown.

The consensus remains that achieving the United Nations Millennium Development Goal of reducing child mortality by two-thirds over the 1990–2015 period will require widespread immunization coverage against infection by preventable diseases (including tuberculosis, pertussis, tetanus, polio, and measles). Controversy persists, however, about the importance of focusing policy on the promotion of specific health interventions versus systems approaches to developing packages of essential services. Achieving the child-survival MDG may require simultaneous attention to a range of prevalent sources of childhood morbidity, such as diarrheal diseases, malaria, acute respiratory infections, and malnutrition. These efforts may interact in ways that prevent immunization from having its intended survival effects. Some proponents of health- systems reform and sector-wide community health services argue that policies focused on promoting specific health interventions are tantamount to abandoning global social and economic health-equity goals (Magnussen et al. 2004). The child-survival effects of maternal educational attainment have been demonstrated for nearly three decades (Caldwell 1979), but questions persist about the efficacy of such focused health interventions as immunization in attenuating these effects (Desai and Alva 1998). Addressing debate about the role of childhood immunization in mitigating the social and economic determinants of mortality remains a critical issue for health policy in Africa. This paper examines the empirical basis for the MDG focus on immunization by testing the hypothesis that immunization offsets the detrimental effects of poverty and low educational attainment in an impoverished rural setting of northern Ghana.

International focus on expanding immunization coverage spans more than two decades of global commitment and action. Adopting immunization as one of its child-survival strategies, UNICEF joined with the World Health Organization in 1986 in pioneering a worldwide global campaign promoting immunization through the provision of technical, financial, and logistical support to developing countries (WHO/AFRO 1994). Subsequently, the United States Agency for International Development joined this partnership with the goal of promoting universal access to immunization against preventable diseases, an effort that was recently joined by the Global Alliance for Vaccines and Immunization (GAVI). As a result of these commitments, most sub-Saharan African countries now incorporate free childhood immunization services in national health-care systems, and many developing countries have registered substantial success in improving immunization coverage. A recent UN (2005c) report estimates that at current levels and trends, governments would require at least 90 percent coverage in immunization in their countries to meet the child-survival MDG by 2015. Coverage levels in many countries in sub-Saharan Africa are far below the 90 percent threshold, however. Ghana exemplifies this problem. Although national coverage rates in Ghana are higher than in other West African countries, with most of the vaccinations exceeding 80 percent coverage, pronounced differences exist within the country by region and district (GSS et al. 2004).

Poverty has also consistently been shown to be associated with childhood mortality. Several studies have demonstrated that the burden of disease is highest among the poorest segments of populations (Wagstaff 2000; Kiros and Hogan 2001; Gwatkin 2002b). The poor are unable to afford curative care, are unaware of the importance of preventive care, and are at greater risk because of their high levels of malnutrition or living arrangements that lower their resistance to infectious diseases (Gadomski et al. 2001). Moreover, the poor and less-educated are less likely than those who are better off to comply with a medical regimen, enhancing their risk of developing antibiotic resistance (Gwatkin et al. 2005).

Although immunization, maternal educational attainment, and poverty are known to covary in many settings, their various independent and joint effects in Africa remain unknown (Attaran 2005). Immunization may offset the effects of poverty by reducing the time and resources parents spend on nursing sick children and thus may divert resources that would otherwise be used in caring for sick children. Immunization programs may provide a basis for addressing health inequity, because the provision of mass immunization does not discriminate between children of the poor and the better-off or the educated and the less-educated. This paper examines data from a district where questions can be addressed about the effect of immunization on the association between poverty and maternal educational attainment and child survival.

THE SETTING

This study is derived from a longitudinal observation of the population of Kassena-Nankana District in northern Ghana, which is ideally suited for such an investigation. In this setting, the Navrongo Health Research Centre (NHRC) has completed more than a decade of longitudinal demographic surveillance of the entire population of the district. Immunization records are also prospectively compiled and linkable to survival histories of children younger than five. Kassena-Nankana District lies within the Guinea Savannah woodland zone of northern

Ghana, where social and economic conditions are among the worst in the country. The district covers a land area of 1,675 square kilometers and lies at the border with Burkina Faso in the Upper East region (see map, Figure 1). Geographic isolation and social deprivation make the district one of the poorest in Ghana. The district is also one of the most arid, with a long dry season punctuated by only three months of rainfall and average monthly temperatures ranging between 20 and 40 degrees Celsius. Thus, the district typifies the harsh environmental conditions of Sahelian West Africa and the challenging circumstances for development in Ghana's northern regions. Although limited irrigation is practiced during the dry season, subsistence agriculture remains the mainstay of the economy.

Demographic and health conditions in Kassena-Nankana District reflect the adverse ecological and economic circumstances of the area. Prior to the health interventions of the Navrongo Centre, the district had one of the highest mortality levels in Ghana (VAST Study Team 1993). Although health conditions were unfavorable in the early 1990s, results from the most recent Ghana Demographic and Health Survey (GDHS) show that both infant and child mortality have declined in the Upper East region in recent years, while conditions have worsened in all other regions of the country (GSS et al. 2004). Fertility and mortality declines are particularly pronounced in Kassena-Nankana District (Phillips et al. forthcoming). Infant mortality declined from 129 deaths per 1,000 live births in 1995 to 85 in 2003, representing a 34 percent decrease, while mortality of children younger than five declined from about 147 to 83 deaths, representing a 44 percent decrease over the period (Binka et al. forthcoming). Although childhood mortality remains high, and infectious diseases are the predominant cause of deaths in the district, all causes of childhood illness have declined, including malaria, diarrheal diseases, acute respiratory infections, and immunizable diseases (Adjuik et al. 2006).

The social, economic, and geographic circumstances of northern Ghana also constrain the delivery of social and health services. The mobility of health services is restricted by the lack of resources for facilities, supplies, fuel, and equipment. Services at stationary facilities in the district are underused because the cost of travel and of services and medicines at clinics is prohibitive for most rural families. Consequently, parents confronting their children's illnesses resort either to traditional medicine or self-medication, purchasing medicines from untrained village hawkers. The innovations derived from research conducted at the Navrongo Health Research Centre have improved the health situation in Kassena-Nankana District over the past several years, however.

THE DATA

Data used for the analysis presented in this paper are drawn from the Navrongo Demographic Surveillance System (NDSS), a system of continuous assessment of demographic dynamics in Kassena-Nankana District (Binka et al. 1999). In 1993, the entire district's population was enumerated and registered in a relational database. At quarterly intervals since July 1993, field-workers visit all dwelling units in the district to update the information obtained in previous rounds regarding changes in household relationships, births, deaths, in- and out-migration, and pregnancies occurring in each 90-day period. Annual updates of immunization status and educational attainment and indicators of socioeconomic status are linked to the demographic register. Data checking and correction are maintained prospectively, allowing for an accurate appraisal of population size and composition, fertility, mortality, and migration.

Data for this paper include information about all 17,967 children born between 1 January 1998 and 31 December 2004. Aggregate mortality rates exhibit childhood-mortality regimes that are typical of Sahelian West Africa (see Figure 2). Risks during the first month of life are double the mortality rates in the postneonatal period. Monthly mortality rates decline monotonically as children age beyond infancy.

In Table 1, mean cumulative immunization coverage rates are shown for each of eight vaccines by age of child for a cohort of Kassena-Nankana children observed over the 1998–2004 period. Except for measles, the proportion of children covered by the various vaccines is around 75 percent or more after the first year. The coverage of measles vaccination is low in the first year of life because measles immunization is usually provided at nine months of age, and most mothers fail to follow the nine-months regimen strictly, waiting until prompted by health workers after their child has passed infancy.

Figure 3 shows the immunization status of all children with respect to all vaccines combined as age advances through the months of infancy. Three categories of children are shown: those not immunized (none), those partially immunized (partial), and those fully immunized (full). WHO guidelines stipulate that a fully immunized child must have received one dose of bacillus Calmette-Guerin (BCG) vaccine (at birth), three doses of poliomyelitis vaccine (at the sixth, tenth, and 14th week after birth), three doses of diphtheria, pertussis, and tetanus (DPT) (at the sixth, tenth and 14th week after birth), and measles vaccine at nine months. Thus, the WHO guidelines for "partial" versus "full" immunization status stipulate that status is to be determined at an age when all vaccinations combined could have an effect rather than at the time that each immunization is administered. Although this definition is useful for the interpretation of cross-sectional survey data, prospectively observed children dying before the time that vaccinations are due are, by definition, "partially immunized" or "not immunized" at the time of death, depending upon whether any vaccine was provided by the time of death (WHO Department of Vaccines and Biologicals 2001).

Models for the analysis presented here are based on the status of each child at the time of last observation with respect to the WHO definition. The observed timing of immunization relative to the WHO-prescribed timing of immunization is illustrated in Figure 3. Although completion of appropriately timed immunization increases monotonically with age, reaching more than two-thirds of all children past infancy, partial coverage of immunization varies as the timing of new steps in the desired regimen are reached. As the figure shows, incomplete immunization increases after the postneonatal period and remains steady throughout the postneonatal months of infancy, even though full coverage advances with increasing age. Because children are often immunized late against measles, a marked increase in incomplete coverage is evident at month nine that declines after infancy.

THE MODEL

The analysis estimates parameters of the proportional hazards model, assuming that the hazard rate for childhood mortality is the product of a baseline failure rate, $h_0(t)$, which is a function of time only, and a positive function $g(x, A)$, independent of time, which incorporates the effects of a vector X comprised of covariates, such as immunization vaccine, mother's characteristics (age and educational attainment), and an index of poverty as estimated by the method of principal components. The conditional hazard is given by

$$h(t/\underline{X}) = h_o(t) \cdot g(\underline{X}, \underline{A}),$$

where

$\underline{X}$ is a row vector consisting of the covariates

$$\underline{X} = (x_{l}, x_{2}, \ldots x_{m}),$$

$\underline{A}$ is a column vector consisting of the effects of unknown parameters of the model, compounded over T units of time

$$\underline{A} = (a_{l}, a_{2}, \ldots a_{m})^{T},$$

and where

m = the number of covariates that are time-independent.

Effects of immunization accumulate with the incremental provision of vaccines as infancy progresses. The immunizations BCG, DPT1, and polio1 are optimally provided in the first six weeks of life, the DPT2 and polio2 are optimally provided in the tenth week, DPT3 and polio3 are provided in the 14th week, and the provision of measles vaccine is optimally provided at nine months. Corresponding effects are posited to accumulate with age t, starting with the baseline failure rate given by the Weibull underlying hazard, with "shape parameter" β:

$$\lambda_0 = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta - 1}$$

and the conditional hazard given by

$$\lambda(t, X) = \beta t^{\beta - 1} e^{\sum_{j=0}^{m} a_j . x_j}$$

The estimation of the shape parameter β and the vector of regression effects, $\underline{\alpha}$, obtained by the method of maximum likelihood (Therneau and Grambsch 2000), are appropriate for specifying the familiar nonlinear relationship of survival with the advancing months of age of childhood.

RESULTS

Hazard ratios presented in Table 2 assess the gross effects of a dose of each vaccine on the hazards of mortality before the age of five. All vaccines exhibit large and statistically significant effects on child mortality. Gross effects are similar, irrespective of vaccine, owing to the intercorrelation of immunizations. Administration of each vaccine is associated with the provision of other vaccines in the immunization regimen. Although some research findings suggest that partial DPT immunization may cause more harm than good (Kristensen et al. 2000), results from Navrongo provide evidence that partial immunization by DPT and polio reduces relative risk by 57 percent.

Table 3 extends the analysis to the multivariate specification with vaccine exposure combined into "full" versus "partial" versus "none". Model I examines the effects of relative poverty and maternal educational attainment on the risk of dying among children younger than five, controlling for the effect of maternal age. Results show that successive quintiles of increasing wealth are associated with monotonically declining mortality risks. Moreover, adding a year of maternal education is associated with reduced relative risk. Clearly, relationships portrayed by the effects of poverty and maternal education in Navrongo are consistent with findings reported from elsewhere in Africa.

Model II tests the hypothesis that immunization offsets the effect of poverty and low maternal educational attainment on child mortality. Results show that introducing immunization into the model is associated with the disappearance of relative mortality effects among all but the most prosperous quintile, suggesting that only children of the most prosperous households benefit from family wealth once immunization status is included as a covariate. The relative magnitude of immunization effects versus poverty effects indicates that immunization has a much greater impact on survival than relative poverty. The risk of dying for children younger than five is reduced by more than 70 percent among those who are fully immunized, compared with those who are not. Partial immunization also prevents mortality.

The relative advantage of children in the uppermost quintile is offset by both partial and full immunization, an interaction that is further demonstrated by Model III, which introduces interactions for the joint effects of poverty quintiles and immunization status. Main effects and interactions suggest that the impact of immunization is greater among the relatively poor than the less poor and more prosperous quintiles, indicating that immunization has a leveling effect on the risks associated with poverty. This conclusion also extends to the relationship of educational attainment with survival, although this leveling effect is less dramatic owing to the metric employed to assess education effects—years of educational attainment. Adding a year of maternal education is associated with about a 3 percent reduction (1.0–0.966) in relative mortality risks when immunization is included in models, fully a percentage point less than the relative risk associated with a year of maternal education when the immunization status is excluded from the model (not shown). Although the effects of low educational attainment are offset by immunization, substantial effects remain even after immunization is included as a covariate. This finding is consistent with the possibility that educational attainment affects parental practices and health-seeking behavior, which, in turn, affect morbidity in ways that are independent of immunizable illnesses.

DISCUSSION

The implications of the pronounced immunization effect on cumulative survival is further illustrated in Figure 4 by a Kaplan-Meier cumulative survival curve depicting the main effects of Model II childhood survival by immunization status (full, partial, or none), with statistical adjustment for maternal age and educational attainment and relative household economic status. For the purpose of the simulation, measles is included as a vaccine in the "full" and "partial" immunization categories. Thus, the Kaplan-Meier estimates combine the effects of full immunization including measles that is estimated in Model II in Table 3. The "none" curve portrays survival when no vaccine or partial immunization in the entire regimen was provided; "partial" refers to any combination of vaccines, including incomplete immunization; and "full" corresponds to the provision of all vaccines listed in Tables 1 and 2. Timing is addressed by assessing immunization status at the last time that a child was observed. Thus, "partial" and "full" immunization includes children whose immunizations were mistimed relative to the WHO-recommended regimen.

As the figure shows, children who have received all vaccinations experience substantially higher cumulative survival odds than their counterparts who are not fully immunized. Those who have received no vaccinations experience catastrophically high cumulative risks of dying by the time they reach age five in this setting, exceeding one-third of all children born. Partial immunization reduces cumulative risk to 20 percent, and full immunization leads to a further reduction of cumulative mortality risk to about 10 percent. Because the estimates portrayed in the figure are based on conditional hazard parameters that are adjusted for maternal age, educational attainment, and household poverty status, results suggest that most of the risk of dying before age five can be eliminated with full immunization in this severely health-deprived setting, which is estimated in Table 3 as a relative risk ratio of 0.084.

Linear combinations of Model III main and interaction effects, presented in Table 4, illustrate the survival implications of childhood immunization for offsetting the effects of poverty on survival. These effects bring into account the possibility that immunization may have contrasting benefits for people at different levels of poverty. Results indicate that children from poor households benefit more from immunization than those from relatively better-off households. For example, the "none" row at the top of Table 4 shows significant improvement in survival at the most prosperous level of wealth relative to the least prosperous. The "full" row at the bottom of the table shows, however, that the pronounced effects of immunization occur equivalently across all poverty categories, corresponding to a reduction in mortality odds in excess of 90 percent relative to the odds for unvaccinated children in the poorest quintile. This equity effect may arise because immunization efforts are launched as a continuous campaign that aims to reach all children without regard for economic category, residence, or social characteristics. Moreover, immunization may have nonspecific morbidity-prevention effects that differentially benefit the nutritionally vulnerable poor (Fine 2005). Although the underlying causes of the equity effect remain unknown, Table 4 provides unmistakable evidence that children living in poverty who are immunized experience pronounced survival gains that equalize their survival odds relative to children from better-off households.

CONCLUSION

Programs intended to address the health needs of children younger than five will require ambulatory health services to deal with the major sources of childhood morbidity and will necessitate health services that are more comprehensive than immunization alone. Nonetheless, results from this research lend strong support to the United Nations' goal of reducing excess childhood mortality among the poor by directing a particular focus on immunization. Results of this analysis also attest to the impact of the immunization program on health equity. Relative poverty has a pronounced effect on the survival of children, even in a setting where nearly all families are poor. This effect of poverty, as well as much of the effect of maternal education, is offset by immunization, lending direct empirical support to policies that promote childhood immunization as a component of poverty-reduction programs.

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Table 1 Status of immunization for eight vaccines, by age of child, Kassena-Nankana District, Ghana, 1998–2004

	Age of child in months			
Vaccine	**0–11**	**12–23**	**24–59**	**All ages**
BCG	56.81	81.46	83.96	75.75
Polio1	54.74	82.64	85.75	76.31
Polio2	43.54	80.26	83.48	71.52
Polio3	33.39	75.64	79.13	65.49
DPT1	46.88	81.20	85.51	73.64
DPT2	38.51	78.73	82.88	69.45
DPT3	28.98	74.72	78.64	63.79
Measles	4.64	63.93	72.92	51.60
Children (N)	(5,124)	(4,655)	(8,590)	(18,369)

Table 2 Univariate time-conditional hazard ratios for the impact of eight vaccines on mortality among children younger than five, Kassena-Nankana District, Ghana

Vaccine	Hazard ratio (confidence intervals)
BCG	0.185(0.169–0.202)***
Polio1	0.160(0.150–0.179)***
Polio2	0.147(0.135–0.162)***
Polio3	0.155(0.142–0.171)***
DPT1	0.149(0.136–0.163)***
DPT 2	0.145(0.132–0.159)***
DPT 3	0.148(0.134–0.163)***
Measles	0.145(0.130–0.162)***

***Significant at p≤0.001.

Table 3 Time-conditional hazard ratios for the impact of immunization and poverty, maternal education, and maternal age on mortality among children younger than five, Kassena-Nankana District

Variable	Hazard ratios (confidence intervals)		
	Model I	**Model II**	**Model III**
Mother's age	0.955(0.920–0.992)*	0.977(0.942–1.055)	0.978(0.943–1.014)
Mother's age squared	1.000(1.000–1.001)*	1.000(0.999–1.000)	0.100(0.999–1.000)
Mother's education	0.958(0.941–0.976)**	0.966(0.948–0.984)***	0.966(0.948–0.885)***
Poverty status			
First quintile (poorest) (r)	1.00	1.00	1.00
Second quintile	0.897(0.786–1.024)	0.969(0.849–1.106)	0.823(0.685–0.988)*
Third quintile	0.844(0.739–0.965)*	0.994(0.870–1.136)	0.973(0.813–1.165)
Fourth quintile	0.802(0.698–0.920)**	0.919(0.800–1.055)	0.723(0.595–0.881)**
Fifth quintile (most prosperous)	0.733(0.630–0.852)***	0.854(0.734–0.994)*	0.672(0.543–0.831)***
Immunization status			
None (r)		1.00	1.00
Partial		0.327(0.294–0.364)***	0.245(0.198–0.305)***
Full		0.103(0.092–0.115)***	0.084(0.066–0.108)***
Poverty-immunization interactions			
First·partial (r)			1.00
Second·partial			1.494(1.094–2.039)*
Third·partial			0.941(0.673–1.316)
Fourth·partial			1.964(1.423–2.711)***
Fifth·partial			1.724(1.213–2.449)**
First·full (r)			1.00
Second·full			1.310(0.925–1.856)
Third·full			1.158(0.826–1.623)
Fourth·full			1.292(0.901–1.853)
Fifth·full			1.510(1.048–2.175)*
Failures (N)	(1,965)	(1,965)	(1,965)
Subjects (N)	(17,967)	(17,967)	(17,967)
Time at risk (months)	31346.63	31346.63	31346.63
Overall p-value	0.000	0.000	0.000

*Significant at p≤0.05; ** p≤0.01; ***p≤0.001. (r) = Reference category.

Table 4 Childhood-mortality hazard ratios for linear combinations of Model III main effects and interactions of poverty quintiles with immunization status, Kassena-Nankana District, Ghana

Immunization status	I (poorest)	II	III	IV	V (most prosperous)
None	1.00(r)	0.823 (0.685–0.988)*	0.973 (0.813–1.165)	0.723 (0.595–0.881)**	0.672 (0.543–0.831)***
Partial	0.245 (0.198–0.305)***	0.302(0.244–0.373)***	0.225(0.175–0.288)***	0.349(0.281–0.434)***	0.284(0.221–0.366)***
Full	0.084 (0.066–0.108)***	0.091(0.072–0.114)***	0.095(0.076–0.118)***	0.079(0.062–0.100)***	0.085(0.011–0.109)***

*Significant at p≤0.05; ** p≤0.01; ***p≤0.001. (r) = Reference category.

Figure 1 Kassena-Nankana District (KND) and Navrongo Health Research Project in relation to the ten regions of Ghana

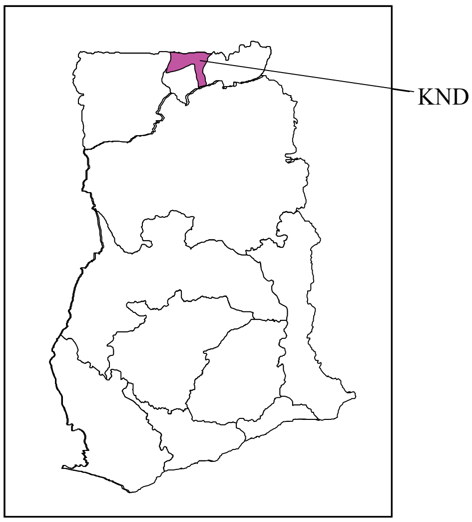


Figure 2: Infant and child mortality rates for children aged 0-59 months, Kassena-Nankana District

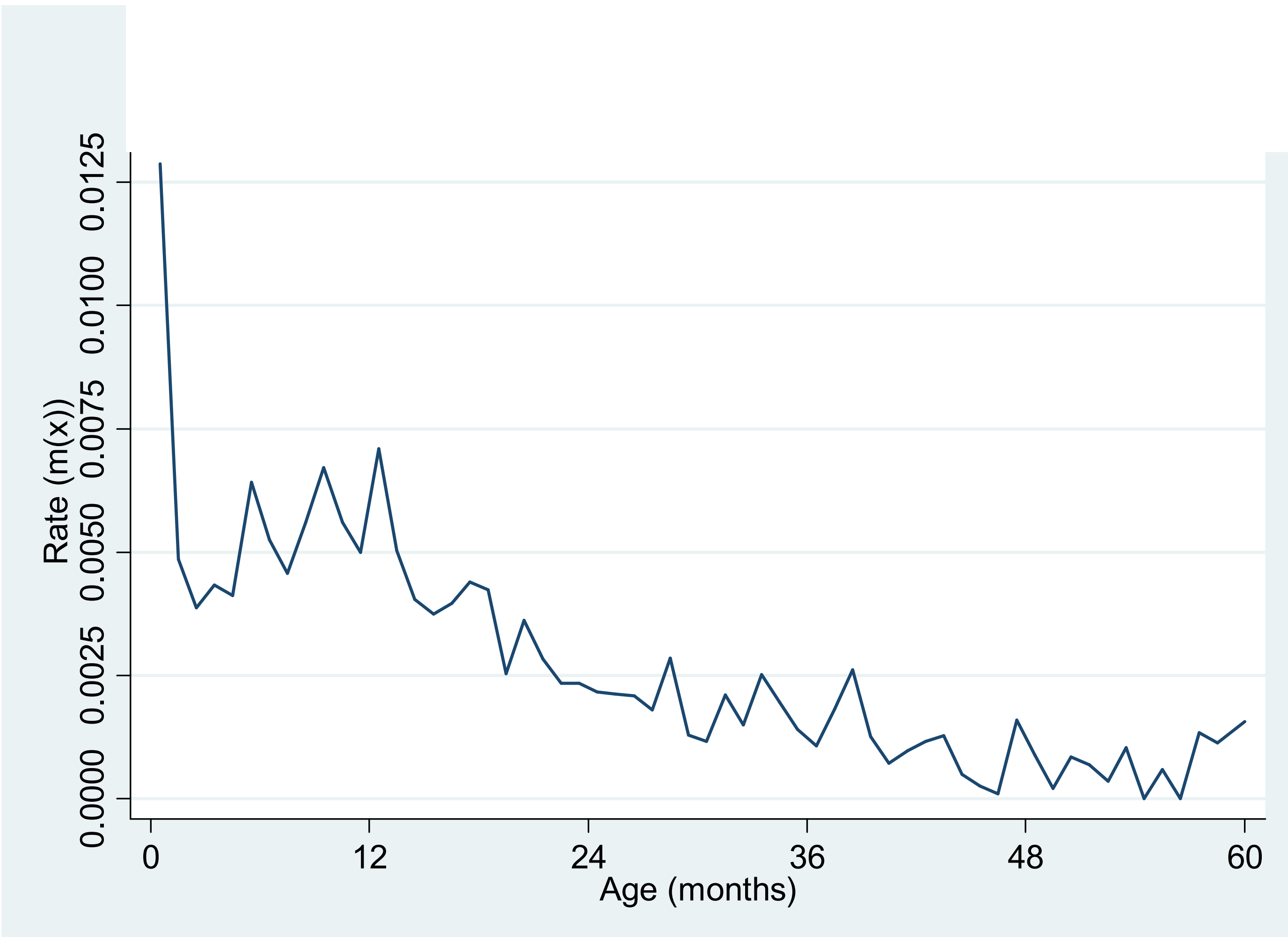


Figure 3 Proportion of children immunized, by age, Kassena-Nankana District, 1998-2004

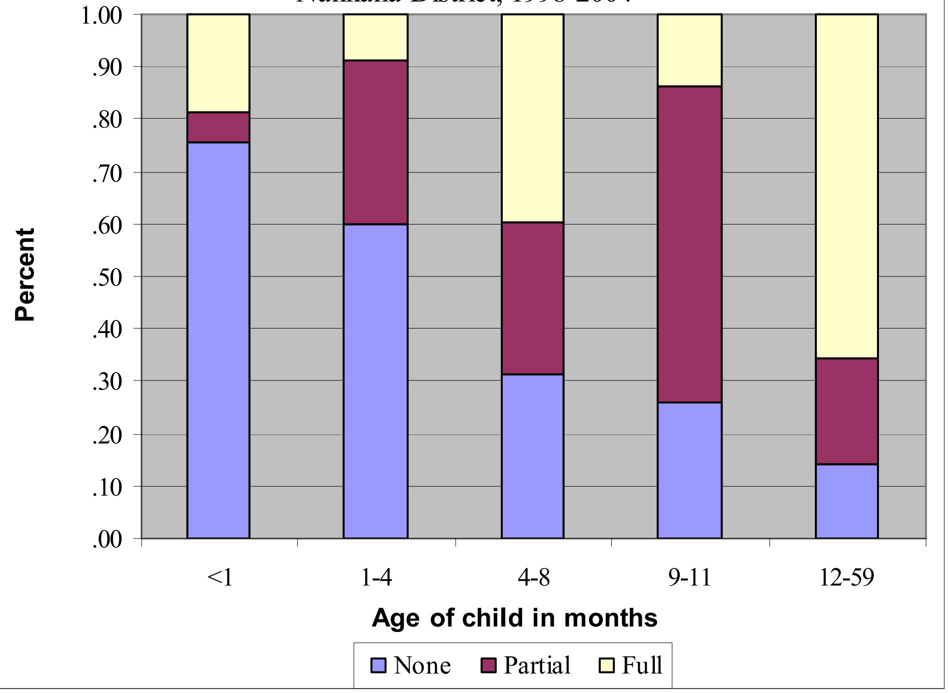
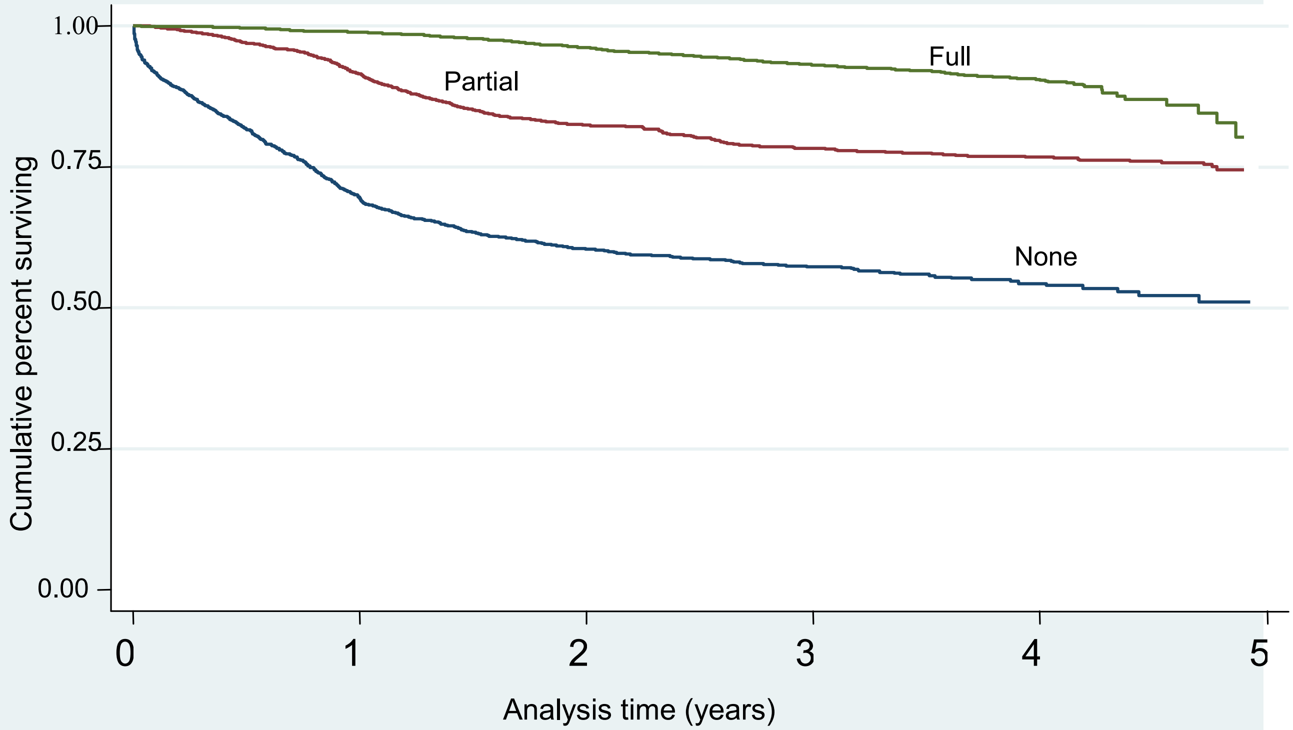


Figure 4 Kaplan-Meier cumulative probabilities of survival, by immunization status of children younger than five



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