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CHILD IMMUNISATION IN GHANA: THE EFFECTS OF FAMILY, LOCATION AND SOCIAL DISPARITY

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Summary. The data from the Demographic and Health Survey conducted in Ghana in 1988 are used to identify determinants of immunisation uptake for children under 5 years. The logistic binomial analysis shows that socioeconomic factors are significant, especially women's education and region, and that the type of prenatal care received by the mother is also important. There is a strong familial correlation of vaccination behaviours, and there is also clustering of data within enumeration areas.

Introduction

Since the worldwide target of 80% immunisation for children was reached in 1990, the task for the Expanded Programme on Immunisation (EPI) is now to maintain high levels of coverage, to strive for a 90% aggregate level by the millennium, and to close the gaps in coverage between nations and between subgroups within nations. In their 1995 report on the 'State of the World's Children', UNICEF (1995a) stressed the development consensus on the latter objectives, highlighting the importance of statistical analysis of social disparity. Studying sub-Saharan immunisation patterns is particularly important in this respect, as these countries have generally not attained the 1990 target and some countries, notably Ghana, have experienced falling coverage levels since that time.

Ghana provides an interesting example of a country whose immunisation programmes made a very successful start in the 1980s but where levels of coverage have proved difficult to sustain. Recently, UNICEF identified Ghana as one of the few countries to report falling coverage over the period from 1986 to 1991 (for example, measles coverage dropped from an estimated 60% to 39% for 1-year-olds over that time) and this is set against a background of significant improvements in most other countries (UNICEF, 1993). Despite more recent evidence of a modest upturn in Ghanaian vaccination rates from UNICEF (1995b) and the 1993 Demographic and Health Survey, the target of 80% child immunisation remains distant in Ghana and a large proportion of child deaths continue to be caused by immunisable diseases, particularly measles. Indeed, estimates of the Ghanaian mortality rate for under-5s do not indicate a decline during the 1980s and early 1990s, in contrast to most other developing countries, including most sub-Saharan African nations.

In order to understand the reasons for such mortality disparities between countries, researchers have identified the need for a closer investigation into mortality and health patterns within countries, especially in association with the introduction of mass programmes such as child immunisation. Mosley (1984) has raised doubts about the effectiveness of vaccination campaigns in terms of their ability to reduce mortality in poor socioeconomic circumstances where uptake is known to be low. This is particularly relevant to Ghana where a wide range of socioeconomic conditions exist. It is important in the first instance to find out which parts of the child population are not immunised. Clearly, a vaccination programme that does not reach children from a poor background may be missing individuals who are under an increased mortality risk from all causes of death. This has serious implications for programme effectiveness if the success of campaigns is to be measured in terms of mortality reduction.

The socioeconomic variables explored in this study are those which have established relationships to infant mortality. These include maternal education (Caldwell, 1979; Cleland & van Ginneken, 1988), place of residence (Dick, 1985), and familial wealth (Anderson & Benham, 1970) as measured through the proxy of father's occupation. The child's sex and maternal age may also influence the likelihood of vaccination (Pillai & Conaway, 1992). The effect of a child's age on vaccination status is likely to depend firstly on whether the child came into contact with health services early in its life, and secondly on the temporal effect of mass immunisation campaigns which may have been more effective in particular years. Recent analyses of immunisation seeking to identify determinants of uptake have also supported the view that maternal education (Pillai & Conaway, 1992; Lanata & Novara, 1991), basic health education for mothers (Streatfield, Singarimbun & Diamond, 1990) and area of residence (Lanata & Novara, 1991) are important factors.

Identifying unvaccinated groups of children within a population is most effectively achieved by applying a regression technique to data on childrens' individual immunisation records and social backgrounds. This method simultaneously takes account of all the significant socioeconomic determinants of vaccination status and quantifies their respective net effects. However, the validity of regression analyses is strongly dependent on the assumption that individual data points are not correlated. In the case of data on vaccination status, it is likely that children within the same family or within the same locality will experience similar risks of remaining unimmunised and therefore traditional regression techniques are not appropriate. Also, it is interesting to investigate the extent to which familial correlation exists and to try to understand local effects on vaccination behaviours which may be due to the presence of health clinics, good outreach teams or even a local culture of positive health attitudes. The effects of these factors can be explained by the application of a logistic binomial model which takes account of the correlations which may exist in the data, as well as providing an accurate estimate of the socioeconomic patterns of vaccination coverage. This is the approach followed in this study.

The major aim of this paper is to identify the socioeconomic factors which predict immunisation uptake in Ghana whilst assessing whether there is evidence for clustering of vaccination outcomes between siblings and between those inhabiting the same locality. The data used are from the Demographic and Health Survey (DHS) performed in Ghana in 1988. From this source it is possible to obtain immunisation details on all six of the EPI-targeted diseases (measles, tuberculosis, pertussis, diphtheria, polio and tetanus) for a nationally representative sample of children under 5 years, as well as information on each child's social and economic background. Analysing DHS data from 1988 provides an understanding of immunisation coverage at a high point of the Ghanaian EPI, after the initial mass programmes in the mid 1980s and during the run-up to 1990.

Data

Data on the health and mortality of children in Ghana were collected as part of the Ghana Demographic and Health Survey (GDHS) which was undertaken between February and June 1988. A self-weighting sample design was used to select 4488 females aged between 15 and 49 years and a subsample of 943 co-resident husbands. Interviews were conducted by trained and monitored local staff using a detailed questionnaire (DHS, 1988). This included complete birth histories for all female respondents. Demographic and socioeconomic information was also collected for women and children along with in-depth data on illnesses, medical care, immunisations and anthropometric details for children. Altogether 3690 living children under 5 years of age were included in the survey.

Of the children aged under 5 years; 18·7% were 4-year-olds, 18·3% were 3-year-olds, 20·6% were 2-year-olds, 21·2% were 1-year-olds and 21·2% were aged under 1 year (of these 47·2% were aged under 6 months). There may be an under-representation of 4-year-olds in the sample due to the backward displacement of births in sub-Saharan African DHS surveys (Freedman & Blanc, 1992). However, this effect (which probably results from interviewers' reluctance to ask the required long series of questions about younger children) is more likely to affect the 5-year-olds which were excluded from the sample used for analysis of immunisation status.

Immunisation data

Vaccination information from DHS surveys has provided an extensive database of information on the immunisation status of living children under 5 in more than 20 developing countries. The large size of the surveys has permitted estimation of the unmet need for vaccination for the whole range of EPI antigens. However, the omission of information on vaccination for dead children does cause problems both in the estimation of coverage levels and also when modelling the socioeconomic and demographic determinants of immunisation uptake. For example, if 95% of children were immunised with the BCG vaccine and the remaining 5% of unvaccinated children all died of tuberculosis, the 100% coverage level estimated from the surviving children would be an overestimate of the true coverage level. Overestimates of uptake will result when, as is likely, the dead children have lower levels of uptake and less complete vaccination protection than the living children. If the socioeconomic predictors of childhood mortality are the same as those for vaccination status then statistical models of uptake based on DHS data will also underemphasise the strength of these determinants. The extent of this bias is not known. It is still possible to use current status data on immunisation in order to estimate true coverage levels although the

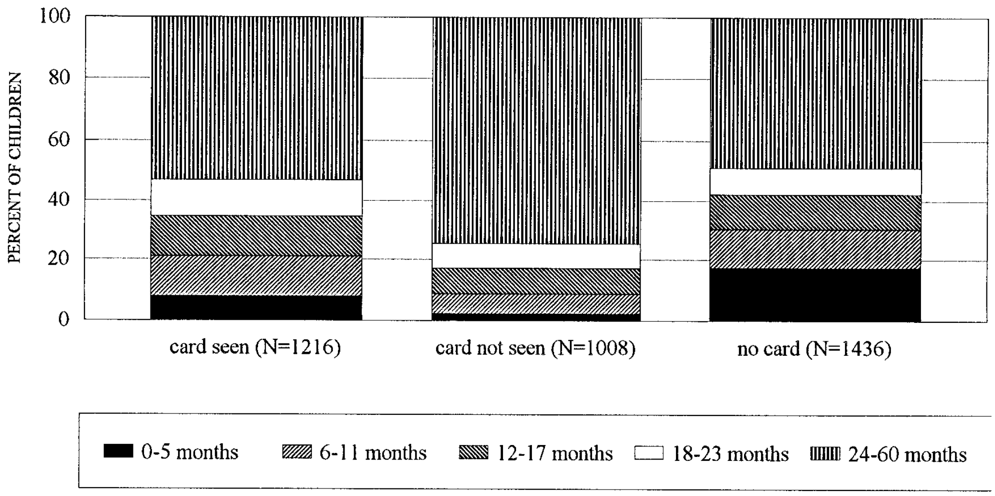

Fig. 1. Age structure of children under 5 years by health card status.

required information for this analysis is not available from the DHS (see Keiding, 1991). Dunn & Yumkella (1990) tried to address this problem by assuming that dead children had the same vaccination status as their siblings, but this assumption is not always valid, especially where a death in the family might change vaccination behaviours.

The main source of information about a child's vaccination history is the immunisation record filled out by health workers and kept by the mother. Data quality from health card information is high, as misreporting or false entries are relatively rare. However, mothers are not always able to produce a health card at the time of the interview, and immunisation information for these children must be based on recall, which can be unreliable. In DHS surveys, vaccination details were recorded by the interviewer directly from the health card. If the mother could not produce the card at the interview, she was asked whether her child had ever been vaccinated. Unfortunately from the 1988 GDHS, it is not known for these cases which vaccines the child had received, so the estimation of coverage rates and the modelling of individual children's vaccination uptake is difficult. This uncertainty is exacerbated in Ghana by low card production rates: many respondents claimed to own a card but could not produce it at the interview. In support of these claims there is some evidence to suggest that the supply of cards in parts of Ghana was patchy during the mid-1980s campaign (Fish, 1986). However, it is possible that in some cases mothers may have been trying to please the interviewers but it is unlikely that this was widespread.

Figures 1, 2 and 3 summarise the information available from the survey with regard to health cards and immunisations. Ghanaian children under 5 years of age from the survey can be roughly divided into three similar sized groups; those whose mothers (a) presented a card at the interview, (b) did not present a card but claimed to own one, and (c) did not have a card. Figure 1 shows that there is a high proportion of 0–5-month-olds with no card presented, presumably because they have not received vaccinations at such an early stage in their lives (although the recommended schedule

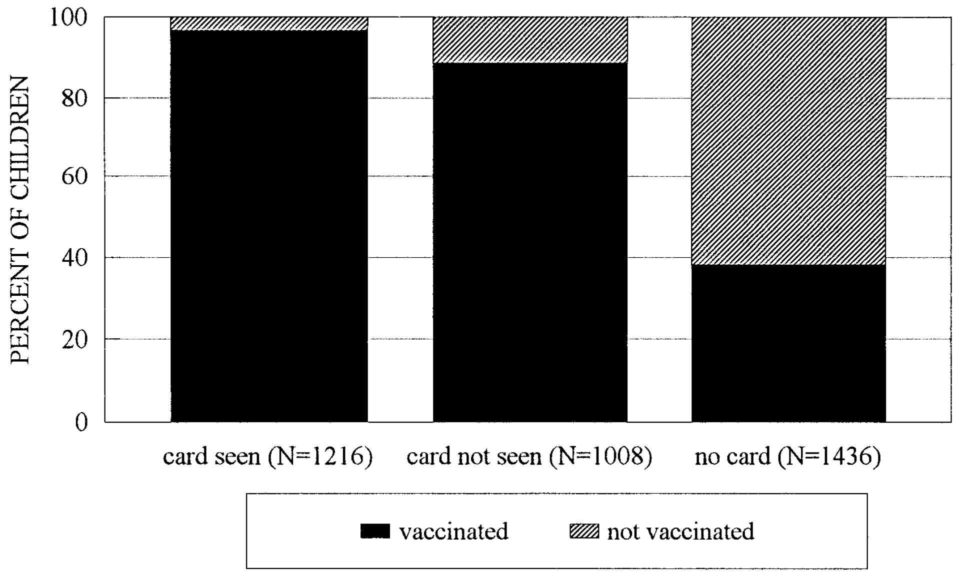

Fig. 2. Vaccination of children under 5 years by health card status.

of vaccination stipulates BCG and polio immunisation at birth in Ghana, and all other antigens except measles to be given by 14 weeks). In addition, the disproportionate number of older children (aged 24–60 months) in the group whose mothers did not produce a card suggests that by this age they have lost them.

The only information about immunisation status for those children whose mothers could not produce a health card is provided by mothers stating whether the child has had any vaccination whatsoever. Again, these data may be biased if mothers tried to please interviewers by claiming that unvaccinated children were vaccinated, thus avoiding any perceived sanctions for not participating in an activity that the government has urged them to undertake. Using these data, Fig. 2 shows that over 60% of children whose mothers did not own a card are completely unvaccinated. Although this is partly caused by the higher proportion of younger infants in the group without cards, the correlation between card-owning and vaccination is clear. For those children with cards that were seen at the interview, it is possible to study vaccination histories in great detail. The survey recorded the date of immunisation for each of the EPI antigens; measles, three DPT doses (triple vaccination—diphtheria, pertussis and tetanus), three oral polio doses and the BCG vaccination (against tuberculosis). From Fig. 3, it is clear that many children over 11 months whose mothers had presented a health card had received all eight of these antigens but more than 50% had not, and that a small percentage had received no immunisation at all. (This result gives an indication of the extent to which there have been missed opportunities for protection.) Some combinations of vaccinations are particularly prevalent; particularly BCG with polio1 and DPT1, or all vaccinations apart from measles. This highlights the problems of dropout from the triple vaccine and oral polio series and also the lack of measles vaccination uptake. A few children (1·9% of card producers over 11 months) are

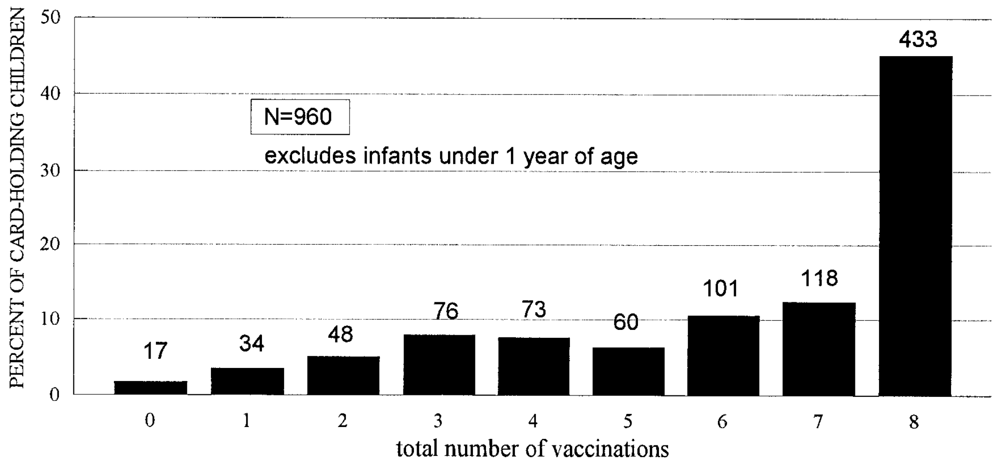

Fig. 3. Distribution of total vaccinations received for children aged 1–4 years with a health card.

recorded as having impossible combinations of vaccines such as BCG, polio1, polio3 and DTP3, which would have resulted from non-sampling errors. Some degree of data quality loss was also apparent in the dates of vaccinations, some of which were coded as before the child was born, or sequential vaccinations recorded in the wrong order. However, evidence from the DHS report on the quality of immunisation data shows that coverage rates estimated from these surveys are compatible with those from other sources (Macro International, 1994).

Socioeconomic and demographic data

A wide range of variables is available from the survey data which may be indicators for vaccination status. Selection of appropriate demographic and socioeconomic predictors was aided by former studies on vaccination uptake and Mosley & Chen's (1984) systematic breakdown of the causative mechanisms which lead to disease and death in children. Fourteen variables were chosen for further examination. The demographic variables considered were; birth order, sex of child, mother's age and child's age. The socioeconomic variables included were; region, area type (urban or rural), mother's education, mother's childhood place of residence, mother's literacy, radio listening, mother's marital status, father's education, father's literacy and father's occupation. Literacy and education were considered separately because they may have different effects on health care, the two variables not always being found to correlate. In addition, a variable was constructed which indicated whether each child had a sibling who had died during the 5 years preceding the survey. This was done to explore the idea that health behaviours are changed by previous deaths in the family.

Radio listening was included in the analysis because radio announcements are frequently broadcast by the Ghanaian government advising parents to immunise their children. Also, evidence from a preliminary examination of the data suggests that there is a tendency for children of radio listeners to be immunised at a higher rate than children of non-listeners. The variable which partitions listeners from non-listeners refers to the mother listening to the radio at least once per week.

Fifteen per cent of the surveyed children under 5 years were born with the help of only a birth attendant or with no trained assistant at all. Clearly, if some vaccinations are recommended to be given at birth, the type of prenatal care received by the mother is likely to affect the immunisation status of her child. Information on prenatal care is available from the survey and was included in the analysis despite the 164 missing values for this variable. The data indicating the father's occupation also included 57 missing cases. It is possible to consider missing cases as a separate category, and this was thought to be appropriate in the case of the father's occupation because the missing group exhibited a particularly low rate of vaccination coverage. However, in the case of prenatal care, the missing cases were not considered to form a coherent and discrete group and they were discarded from the analysis.

Figure 4 illustrates the cross-tabulations between vaccination status and some of the chosen variables. A vaccinated child is defined here as one whose mother either has a card to prove their vaccination status or she has answered yes to the question which asks if the child has ever been vaccinated. Thus the type of vaccinations that have been given are not always specified and it is not always known how many of the recommended antigens the child has received. However, these data do highlight those children who have had no vaccination whatsoever. Children whose fathers are agricultural workers and whose mothers have no education, and those who live in rural locations in the Northern regions are more likely to remain unimmunised (Fig. 4). Clearly there is regional variation within many variables, especially father's occupation, mother's education and location type: the Greater Accra and Northern regions are at opposite ends of the spectrum, with Greater Accra being more urban, more educated and with few agricultural workers, the converse being true in the Northern regions.

Information on families and locations

From the DHS data it is possible to establish which individual children are siblings as well as the enumeration area in which the children live. These are the two aspects of the data which may cause clustering of individual outcomes. Enumeration areas from the 1984 census are used to represent the locality clustering in this analysis and although some of these districts contain diverse populations and their physical sizes vary considerably, the effect of the proximity of health facilities and local health knowledge can be explored. One hundred and fifty enumeration areas were sampled during the survey and from a preliminary examination of the data there is some evidence to suggest that children's vaccination status is affected by which enumeration area they inhabit. The areas themselves have an average of 23 children each from the survey, although the number varies from 5 to 69 children per area. The areas are also characterised by respondents from different socioeconomic backgrounds. For example, there are many areas where none of the mothers have received secondary or higher education, and some where very few of the fathers have a white collar occupation. However, it is not clear from a preliminary analysis whether there is additional clustering of vaccination behaviour within enumeration areas which is not explained by these factors.

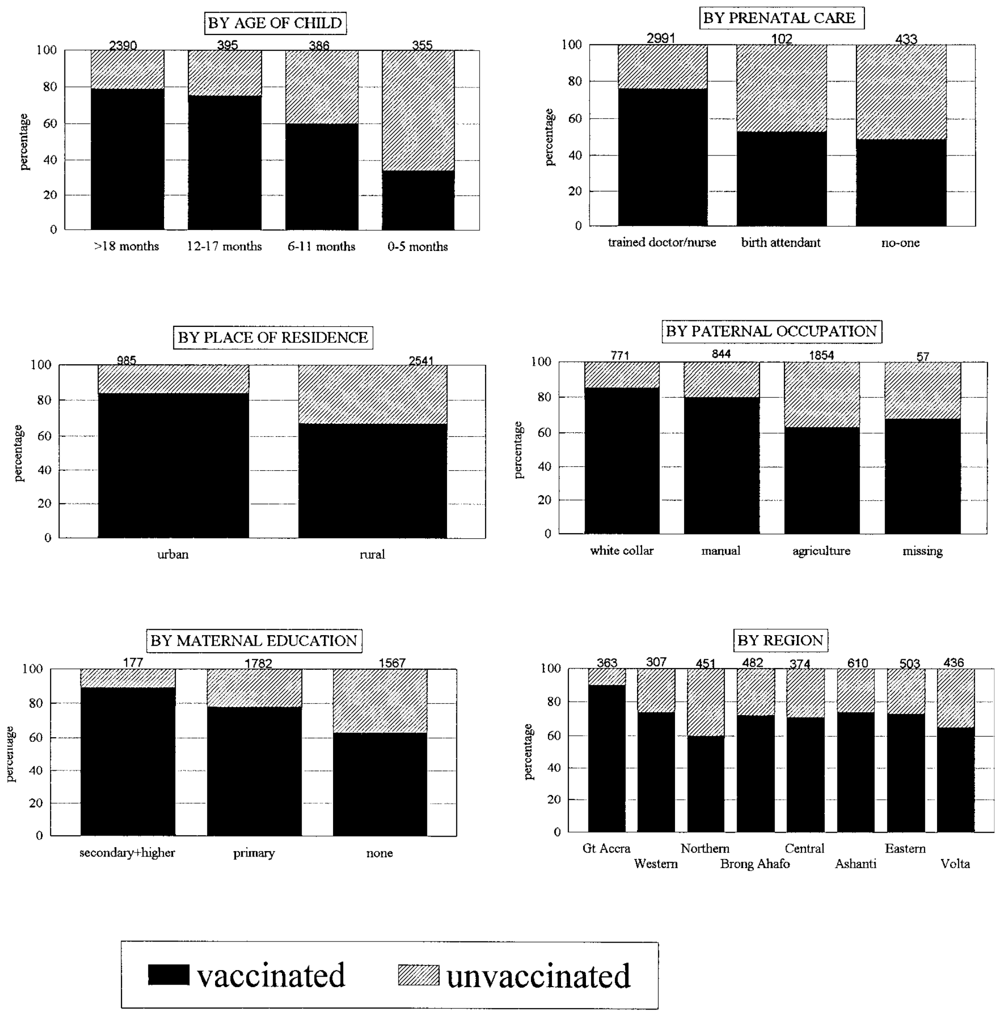

Fig. 4. Vaccination status of children aged under 5 years by various characteristics.

There is also some evidence of correlation within families, although family size is very small in comparison with enumeration area size and many mothers had only one child under 5 years of age at the time of the survey; 42% of the children in the survey were the only child under 5 years in their family. However, due to the short birth intervals in Ghana, many of these children are likely to be young, first born children. The correlation structure within families has the extra dimension of the child ordering, which may be relevant in terms of vaccination behaviour.

Intuitively, mothers who have their first child vaccinated should do the same for their second, and so on. Evidence from the survey suggests that vaccination rates tend to diminish with larger family size. There is also a lower rate of immunisations among younger siblings than among older siblings but this effect is due to the very low

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Table 1. Odds ratio of being vaccinated for sibling pairs

	Lag 1	Lag 2
All sibling pairs	8·8	6·6
Pairs >11 months old	14·6	5·3

proportion of younger children with vaccinations rather than a change from vaccination to non-vaccination within families. Further analysis which omits infants (thus controlling for the age-effect) shows that where a child exhibits a different immunisation status from its sibling, the changeover is likely to be from an older unvaccinated child to a younger one who is vaccinated.

The odds ratios presented in Table 1 indicate the autocorrelation structure in families. These ratios were calculated using the vaccination status of sibling pairs, those for lag 1 being adjacent siblings (1053 pairs) and those for lag 2 having one sibling between the two (76 pairs). There is a strong chance that siblings have the same vaccination status, and this is even more apparent when infants are not included. There is less correlation at lag 2, and fewer data from which to calculate correlations, but the results are still statistically significant. These preliminary calculations suggest that family clusters of vaccination behaviour do exist in the data.

Method

The scope for investigating immunisation uptake against specific childhood diseases is very limited from these data, because of the lack of health cards presented during the survey. This is unfortunate, as it would have been instructive to compare the determinants of measles vaccination uptake with those of other antigens which have shown higher coverage rates. However, it is possible to use vaccination status as a response variable; the dichotomous outcome being whether or not each child has been vaccinated against any EPI-targeted disease. This approach is preferable to focusing on card ownership, as this indicator may be influenced by the local effects of health system administration.

Having chosen an appropriate outcome variable, an assessment of the relative magnitude of socioeconomic and demographic influences on coverage may be obtained by applying a logistic regression analysis to the data for children under 5 years using the socioeconomic characteristics available from the survey as predictors for unvaccinated children. Fitting traditional logistic models, however, involves problems when using data with a hierarchical structure. Clusters of health behaviours occur within families as well as within localities, and this can undermine the assumptions necessary for the application of simple logistic regression models. These models assume the independence of individuals in the sample, and the logistic model in particular assumes that all of the variation in the probabilities modelled can be completely explained by the covariates. However, in the case of vaccination status, there is likely to be a correlation structure because mothers tend to treat siblings in a similar way, and because vaccine uptake may be dependent on the accessibility of clinics in the immediate area. An alternative to fixed-effects models was therefore sought to eliminate the problems of clustering as well as to find out the extent to which familial and location-based health behaviours affect vaccination status.

Recent analyses of DHS data have used ‘random effects’ models to incorporate clusters into the model-building process, and to assess the extent of the cluster correlations (e.g. Madise & Diamond, 1995; Curtis, Diamond & McDonald, 1993). Two such models were applied in this study: the first allows correlation between vaccination behaviours within families (so that children with the same mother were allowed to exhibit clustered observations) and the second allows correlated behaviours within enumeration areas (in order to measure and allow for a location effect). Random effects models include the fixed effects of the standard case but with an additional random perturbation to explain the unobserved higher level effect. This extra variance component is assumed to have some distribution across the population defined by a fixed number of parameters. Various random effects models have been proposed for binary data including probit and log-log formulations. However the logistic model chosen for this analysis can be expressed as follows:

$$\text{logit}\,(p_{ij}) = \mathrm{X}_{ij}^{\mathrm{T}}\beta + \sigma\, u_i$$

where p_{ij} is the probability of not being vaccinated for the jth child in the ith family or location, X_{ij} is a vector of explanatory variables and β is the corresponding vector of coefficients. (The emphasis on unvaccinated status in this formulation is for ease of interpretation and helps to identify children who have not been immunised and therefore need to be targeted.)

The model is the same as the standard fixed effects logistic regression with an added u_i which is the random perturbation associated with the ith family or location; u_i is standardised in the equation above with σ as scale parameter where $\sigma \geq 0$. The random term models the unobserved group effects and allows for covariates at the individual level (sometimes called ‘distinguishable’ data; a covariate may take different values in the same family or location). The main issue for model selection is which distribution to assume for the u_i. In this study a logistic binomial approach was used which means that u_i is assumed to take a binomial distribution.

Model fitting was performed by forward selection. The same proximate and socioeconomic variables were tested for significance in both models, a fixed effects model having been fitted to the same set of variables prior to embarking on the random effects formulation. A one-tailed normal test was used to determine the significance of the random terms. The standard likelihood ratio test statistic was used for hypothesis testing during the model fitting procedure. This is equivalent to testing the difference in deviance between the postulated models with and without a covariate of interest, against a chi-squared distribution, and is the usual procedure for such models (McCullagh & Nelder, 1989).

Results

The search for significant covariates yielded the same set of factors in the random effects models as in the initial fixed effects estimation, i.e. no extra variables were found to be significant in the random effects models, and no variables that had been

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Table 2. Coefficients and odds ratios for a logistic binomial regression with random effect at mother level to predict unvaccinated children

Variable and category	Estimate	Odds ratio	*N*
Age of child (months)			
> 18		1·00	2390
12–17	0·52 (0·21)	1·68	395
6–11	1·95 (0·23)	7·02	386
0–5	3·79 (0·30)	44·19	355
Place of residence			
Urban		1·00	985
Rural	0·69 (0·21)	1·99	2541
Mother's education			
Secondary/higher		1·00	177
Primary	1·09 (0·48)	2·97	1782
None	1·98 (0·50)	7·22	1567
Father's occupation			
White collar		1·00	771
Manual	0·54 (0·26)	1·72	844
Agricultural	1·25 (0·25)	3·50	1854
Never worked/don't know/missing	0·95 (0·62)	2·59	57
Region			
Greater Accra		1·00	363
Western	0·92 (0·43)	2·50	307
Upper/Northern	1·13 (0·42)	3·08	451
Brong Ahafo	1·00 (0·40)	2·73	482
Central	1·25 (0·41)	3·48	374
Ashanti	1·41 (0·39)	4·11	610
Eastern	1·51 (0·40)	4·54	503
Volta	1·69 (0·41)	5·43	436
Prenatal care			
Trained doctor/nurse		1·00	2991
Traditional birth attendant	1·78 (0·41)	5·93	102
None	1·46 (0·23)	4·31	433
Random effect	2·27 (0·20)		

Total deviance on model is 3311·7 on 3492 df.
Standard errors in parentheses.

established in the fixed effects model were found to lose significance. The significant factors were: child's age, place of residence (urban or rural), mother's education, father's occupation, region and type of prenatal care. The sex of the child, birth order, mother's age, radio listening and previous deaths of siblings within the family were not found to be significant predictors of vaccination status. Clearly, the demographic variables have less explanatory power than the socioeconomic variables. A significant random effect was present in both models.

Odds ratios for the family cluster model can be seen in Table 2, and those for the

Table 3. Coefficients and odds ratios for a logistic binomial regression with random effect at location level to predict unvaccinated children

Variable and category	Estimate	Odds ratio	*N*
Age of child (months)			
> 18		1·00	2390
12–17	0·28 (0·14)	1·32	395
6–11	1·22 (0·13)	3·38	386
0–5	2·40 (0·14)	11·06	355
Place of residence			
Urban		1·00	985
Rural	0·50 (0·17)	1·64	2541
Mother's education			
Secondary/higher		1·00	177
Primary	0·61 (0·30)	1·83	1782
None	1·11 (0·30)	3·02	1567
Father's occupation			
White collar		1·00	771
Manual	0·41 (0·15)	1·50	844
Agricultural	0·72 (0·14)	2·06	1854
Never worked/don't know/missing	0·66 (0·36)	1·94	57
Region			
Greater Accra		1·00	363
Western	0·82 (0·35)	2·27	307
Upper/Northern	0·83 (0·34)	2·29	451
Brong Ahafo	0·78 (0·33)	2·18	482
Central	0·90 (0·34)	2·47	374
Ashanti	0·93 (0·31)	2·53	610
Eastern	1·14 (0·32)	3·12	503
Volta	1·13 (0·34)	3·10	436
Prenatal care			
Trained doctor/nurse		1·00	2991
Traditional birth attendant	1·04 (0·23)	2·83	102
None	0·88 (0·14)	2·40	433
Random effect	0·59 (0·07)		

Total deviance on model is 3389·7 on 3492 df.
Standard errors in parentheses.

location cluster model in Table 3 although care must be taken when interpreting these figures. Because of the addition of the random element to the model, a distribution is assumed across each family or location which is centred about the fixed effect. This means that odds ratios relate only to ratios of average probabilities for each set of socioeconomic characteristics. Odds ratios in the presence of a significant random term may also be interpreted as the odds of being unvaccinated within the particular family or location.

Odds ratios from the location cluster model are slightly higher than those from the fixed effects case, although the difference is never more than 1, thus showing the relatively small effect of location correlation. However, the most marked departures from the standard case appear in the family cluster model, where odds ratios are appreciably higher for child's age, maternal education, prenatal care and region. These results show that the assumption of independence in child vaccination status cannot be made where siblings are included in the analysis, and that location also affects uptake. Those factors which relate to the mother, such as education and prenatal care, are particularly affected by familial correlation.

After controlling for the child's age, the strongest effects are from maternal education, with an odds ratio of 7·22 for those with no education compared with those with secondary schooling or more in the family cluster model. The operation of this factor is likely to be through improved knowledge and understanding of modern preventive health care via education, although a higher level of education could also bring knowledge of, and improved access to, local health facilities. Regional differences are also marked. The inversion of the expected regional order is interesting with Volta showing the highest odds ratio, rather than the Northern (Northern, Upper East and Upper West combined) or Central regions, which, in 1988, had considerably higher child mortality rates and lower health service coverage levels than the rest of the country. This indicates that the socioeconomic makeup of the traditionally high risk regions may account for their low vaccination rates. It is also possible that the prevalence of traditional religious practices in Volta region has made vaccination unpopular in that region. However, the odds ratios for regions other than Accra in this model are very close, so the ordering produced is not statistically significant.

The effect of women having a trained doctor or nurse involved with prenatal care has the expected effect on the vaccination status of their children. In these cases it is likely that medical personnel urge mothers to immunise their children and health cards may be issued at the time of the birth. It is surprising that BCG coverage is not more universal as a high proportion of children's mothers were attended by trained medical staff at birth, and the BCG vaccination is recommended at birth. The odds ratio for traditional birth attendant in the family cluster model is 5·93, higher than that for no birth attendant, which may seem counterintuitive, although the difference between these two categories is not significant.

As in previous studies of mortality and health coverage, urban children have the advantage over rural children, the odds ratios for this variable showing similar levels for both models. The magnitude of the effect is lower than for other explanatory factors, however, and this may be partly due to the urban advantage being diluted by the low coverage levels within areas of urban poverty. Father's occupation also has explanatory power, and this underlines the importance of familial wealth and resources to child health. Women earn money independently by market trading in many parts of Ghana, and these resources are likely to contribute to children's health care costs, but fathers are still the principal breadwinners in Ghanaian society, and fathers' occupation is indicative of the general wealth and status level of a family.

The effect of clustering in families is greater than that in enumeration areas: the random term for the family cluster model is 2·27, and that for the location cluster model is 0·59 (Tables 2 and 3). The effect of these parameters can be shown by calculating the probabilities of no vaccination for a child with a given combination of characteristics, using a range of different realisations of the random effect u_i. This gives

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Table 4. Estimated probabilities of having no vaccination for children with baseline characteristics and for those with least favourable characteristics by different values of random effect

Value of random component (u_i)	Mother component model		Location component model	
	Baseline characteristics	Least favourable characteristics	Baseline characteristics	Least favourable characteristics
−2	0·0000	0·0134	0·0042	0·2425
−1	0·0001	0·1161	0·0075	0·3661
0	0·0011	0·5597	0·0134	0·5102
1	0·0104	0·9248	0·0239	0·6527
2	0·0920	0·9917	0·0423	0·7722

an idea of the distribution of probabilities within different families or locations. For illustration, these probabilities have been calculated for a child with the most favourable combination of characteristics, and also for a child with the least favourable characteristics (Table 4). The most favourable set of characteristics is the baseline category: children aged greater than 18 months, from an urban area in Greater Accra, who have mothers with secondary education or higher, fathers with a white collar job and whose mothers received prenatal care from a trained doctor or nurse. The least favourable characteristics are the opposite: children aged 0–5 months, from a rural area in Volta region, who have uneducated mothers, fathers with an agricultural job and whose mothers received no prenatal care.

The median probability of no vaccinations across families (corresponding to $u_i = 0$) is 0·0011 for a child with the favourable characteristics and 0·5597 for a child with unfavourable characteristics (Table 4). The corresponding estimates across locations are 0·0134 and 0·5102. However, there is a large amount of variation for children with the same characteristics in both models because of the significance of the random effect. This variation is illustrated by the range of values seen between low risk families and locations ($u_i = -2$) and high risk families and locations ($u_i = 2$), especially for the children with unfavourable characteristics. For example, for a child with the least favourable characteristics, the chance of remaining unimmunised could range from 0·0134 to 0·9917 depending on which end of the distribution the family lies. Clearly there are factors operating which determine which end of the spectrum any particular family may be, but they have not been identified by these data. Also, the range of probability values is smaller across locations than across families, demonstrating the stronger effect of the random term in the family cluster model than in the location cluster model.

Discussion and conclusions

This study of the determinants of immunisation uptake in Ghana has shown that vaccination behaviours cluster within families and to some extent in locations. The standard approach of fitting regression models to child level data where siblings and children from the same locality are included is thus inappropriate in this case. After applying a random effects analysis which takes account of these correlation structures within the data, the socioeconomic predictors of unvaccinated children are shown to be very important, especially maternal education, region and type of prenatal care. The effect of social disparities existing within Ghana during the late 1980s can thus provide a useful explanation for the low immunisation coverage rates at that time.

However, the explanation of immunisation by those socioeconomic predictors that were available from the survey data is not complete. The clustering of vaccination behaviours within families effectively means that although children from families with favourable socioeconomic characteristics have a high probability of being immunised, the chance of vaccination in families from unfavourable backgrounds varies considerably according to some unknown factors. This is also true to a lesser extent in localities as represented by census enumeration areas. The weaker effect of clustering within locations must be partly due to the lack of homogeneity of the populations within each area. There may be good access to a health facility in one part of an enumeration area but not in another. The growth and change of local area populations in Ghana since the last census may also cause distortions in these data. However, the evidence for a local clustering effect suggests that unexplained factors should be sought at this level as well as at the family level. Indeed a more detailed understanding of the variation across families and locations may provide the key to more successful programme implementation in the future.

The importance of maternal education to child health is underlined from the results of this study as from previous work and numerous analyses of infant and child mortality. Ghana's record of improvement in educational coverage is substantially above average in the sub-Saharan context with 55% of female children now reaching at least grade five of primary school (UNICEF, 1994). However, it may be too early for the effects of these improvements to effect a noticeable change in vaccination behaviours in the maternal population. Under-5 mortality rates seem similarly unaffected by improved educational levels in recent years; estimates made during the 1980s and 1990s suggest that there has been no decrease in mortality in Ghana in contrast with most other sub-Saharan African countries. The severe economic crisis during the 1980s undoubtedly had an effect on these trends and may have also influenced immunisation uptake in the 5 years before the survey.

Maternal education and familial wealth are primarily demand factors on vaccination coverage in that they affect the likelihood of parents to seek immunisation protection for their children. From the results of this analysis, supply factors can also be seen as important. Regional differentials and urban–rural disparities reflect the range of campaign effectiveness across the country and the unexplained location effect is likely to involve the supply variation between enumeration areas. Using ideas of supply and demand provides a useful framework within which to understand vaccination uptake, especially in terms of policy implications. Local studies in Ghana (e.g. Fish, 1986) quote a number of logistic difficulties of the EPI campaign which can be designated as supply or demand factors. Prominent amongst these problems are: low motivation to immunise amongst rural mothers in remote areas, difficulties with roads, transport and vaccine supply and problems in recruiting and keeping medical staff in rural areas where infrastructure is poor. An understanding of the relative importance of these and other factors is necessary to explore unexplained location and family effects. On a national level, the history and persistence of low vaccination uptake, although exacerbated by disparity of demand, may be determined largely by supply factors. In support of this, disparities of a similar magnitude to those reported in this study can be observed in countries with a higher overall rate of uptake (Boerma *et al*., 1990).

In summary, the results of this study suggest that the closing of socioeconomic gaps within the Ghanaian population, particularly with respect to women's education, would aid vaccination coverage. The translation of immunisation coverage to lower mortality rates is not likely to operate smoothly without addressing social disparity. The risk groups identified by the high odds ratios from the analysis could be a special target for immunisation campaigns. However, more work is necessary to find out the factors which are causing particular families and localities to exhibit low uptake. A supply- or demand-oriented approach could then be taken in future campaigns, with supply deficiencies met by better organised services, or demand shortfalls answered by education and incentives where the priority to immunise children is low on the family agenda.

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