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Demand for Immunization, Parental Selection, and Child Survival: Evidence from Rural India*

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Abstract. This study focuses on the estimation of demand for immunization as well as its technological effect on the survival probability of a child in rural India. Careful attention is paid to the consequences of parental selection on survival technology and demand for health inputs. The results suggest that child mortality is negatively related to the likelihood of purchasing vaccination, but imperfect vaccination substantially reduce the beneficial effect. Results also suggest that a mother who perceives her child faces a risk of higher likelihood of death compensates for their beliefs in a beneficial way. Consequently, estimations that ignore this selection underestimate the impact of immunization on child survival. Mothers also engage in complementary behavior by reinforcing investment when they choose among health inputs. Estimations that ignore the complementarity substantially overstate the impact of prenatal care and delivery care on demand for immunization. The evidence for complementarity among measured inputs also implies that there might be favorable selection between measured and unmeasured inputs, although the adverse selection seems dominant in this study.

Keywords: immunization, self-selection, household production, health inputs

JEL Classification: I12, J13

1. Introduction

Many researchers have tried to explain what causes infant and child mortality to decline in a demographic transition. The prevailing view is that improvements in public health-care technology and the introduction of new health-care systems play important roles. For example, the universal immunization programs, which are often referred to as "the most cost-effective route to child's better health" (World Health Organization: WHO, 1998), surely had a large impact. The goal of this paper is to estimate the immunization demand function and the impact of immunization on the probability of child survival in a household production framework. In order to achieve the goal, the study addresses the following issues.

First, careful attention is paid to issues of consequences of parental selection on survival technology. Research on demand for health care shows that self-selection

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exists in the demand for prenatal health care and illustrates the biases that occur when the impact of self-selection is not considered. Michael Grossman and Theodore J. Joyce (1990) and Constantijn W.A. Panis and Lee A. Lillard (1994) identify two sources of potential bias due to self-selection. The first source of bias stems from *adverse selection*; which occurs when the decision to buy a certain health input is triggered by the desire to compensate for an inherent endowment deficiency. For example, a pregnant woman may seek earlier prenatal care based on the knowledge of the health endowments in either both parents or from previous experience with her other children. The second source of bias stems from *favorable selection*; which describes the case where omitted exogenous biological factors or endogenous inputs such as an individual's overall fitness level or eating habits may be positively correlated with the error term in the demand for health care, which measures risk aversion. A woman with lower stress levels or higher degrees of risk aversion, for example, may have better health outcomes and may also get more prenatal care and more of the unobserved inputs. Similar to parental selection in the demand for prenatal care, postnatal care such as child immunization might be conditioned on both types of selection. The mother's selection of child immunization might also be conditioned on birth outcomes and histories of disease occurrence, since mothers will adjust their behavior when they observe these. These selections influence observed mortality, since a child's immunization coverage will depend on a rational mothers' selection.

Second, representing the mother's criteria in selecting health inputs is an issue. There are a variety of aspects of this effect. One aspect of this effect is *learning-by-doing*. Participation in a program or a system yields information to the individual which influences subsequent assessments about the benefits and costs of continued participation. For example, a participant in prenatal care may learn about the value of delivery in a modern clinic or the value of child immunization or learn about how the health system operates, thereby reducing the costs of accessing the system. Another aspect of this effect is *complementarity*. It is likely that a mother who chooses prenatal care may also engage in complementary behavior such as immunization. When the presence of complementary behavior is ignored, the correlation among the disrubance terms of measured inputs may overstate the effect of prenatal care on the demand for immunization.

Ignoring complementarity among measured health inputs may overestimate the effect of prenatal care on immunization. Although ignoring complementarity does not bias the estimated coefficients in the survival production function, its existence between measured inputs may imply the possibility of favorable selection between measured and unmeasured inputs. That is, evidence for complementarity may also imply there is favorable selection between measured and unmeasured inputs even in cases when adverse selection is dominant.

The study also addresses the issue of partial (imperfect) immunization due to either dropout or skipped vaccinations. The failure to obtain additional immunization might result from several factors: a lack of awareness, an experience of complications after immunization, and/or shortage of vaccine supplies. These factors may be related with the state-dependency problem in immunization. For example, a mother has a strong incentive to have her child vaccinated at the early stage of a child life since the hazard of mortality is highest and a mother is better informed. However, this incentive might get weaker at later stages of the child's life. The impact of the imperfect immunization on the probability of child survival is examined.

This study uses the 1992–1993 National Family Health Survey (NFHS) in India. In India, the immunization of children against six fatal but preventable diseases (tuberculosis, diphtheria, whooping cough (pertussis), tetanus, polio, and measles) has been an important cornerstone of the child health-care system since its first introduction to the country in 1978 (WHO, 1986).[1] The 1992–1993 survey data contains detailed histories of a child's immunization as well as considerable information on socioeconomic, demographic and community measures. This study uses this information to estimate a child's health production function focusing on children born in the period 12–48 months before the survey. In order to construct a variable measuring per capita household expenditure, the 1993 (50th round) National Sample Survey (NSS) in India is also used. The log of per capita household expenditure is imputed based on household head's occupation, education, age, and residence using the NSS and merged into the NFHS.

In the next section, a household decision model is constructed in which immunization explicitly enters as a postnatal input in a child survival production function. Data and sample selection are discussed in Section 3. Section 4 reports estimates of the effect of immunization on child survival as well as the effects of demographic and socioeconomic variables on demand for child immunization. Section 5 summarizes the study.

2. The model

Several researchers have modeled production functions which consider the unobserved heterogeneity (Michael Grossman, 1972; Randall J. Olsen and Kenneth I. Wolpin, 1983; Mark R. Rosenzweig and T. Paul Schulz, 1983; Mark R. Rosenzweig and Kenneth I. Wolpin 1995, 1988; Kenneth I. Wolpin, 1997). Consider a household which exercises choice over consumption, the number and quality of surviving children given budget constraint. The number of surviving children is produced by inputs into a survival production function. Each child of the household has inherent family endowment which contains family specific genetic and environmental attributes affecting a child's mortality.

It is assumed that the selection of health products is cumulative and there are three instances in which parents can select health inputs for their child: prenatal, at delivery, or postnatal. These variables can also be referred to as health production inputs followed by the tradition of the Gary S. Becker (1965) model. Overall susceptibility to a certain disease would depend on mother and child's biological characteristics, nutrition and feeding, and mothers' prenatal, delivery, and postnatal behavior which are preventive, curative or both. The survival probability of a child of a mother at a certain time of life is then given by the following survival production function.[2]

$$S_t = \Gamma(t, T^1, T^2, T^3, x, \mu), \quad (1)$$

where the t is the child age, T^1, T^2, T^3 are respectively, the mother's prenatal behavior (T^1), delivery behavior (T^2), and postnatal behavior (T^3) until child age t-1, x is a vector of biological and nutritional characteristics which affect a child's postnatal probability to survive, and μ family endowment.

The household reduced form demand functions for inputs T^1, T^2, and T^3 can be derived from the maximization of the household utility function. Consider immunization as only postnatal health care behavior. The reduced form demand functions can be written as

$$T^i = \Psi^i(p, M, z, \eta^i, \varepsilon^i) \quad i = 1(\text{prenatal}), 2(\text{delivery}), 3(\text{immunization}), \quad (2)$$

where p represents prices of all goods, M household income (or expenditure), z other household and community characteristics that affect the demand for inputs, η^i represent mother's selection terms in each demand functions, and ε^i represent a history of shock until event i, which might affect mother's behavior. For example, mothers come to know the gender of child at delivery, which affect their demand for immunization. The confounding relationships between equations thus can be best summarized as $Cov(\eta^i, \varepsilon^{i+t}) = 0, Cov(\eta^{i+t}, \varepsilon^i) \neq 0, Cov(\eta^i, \mu) \neq 0$, and $Cov(\eta^i, \eta^j) \neq 0$. Each relationship is discussed in turn.

First, it is natural to have $Cov(\eta^i, \varepsilon^{i+t}) = 0$ with time $t > 0$, because it is by definition unforeseen by parents before behavior i occurs.

Second, mother's selection of child immunization might be conditioned on birth outcomes and other shocks or disease experienced by her child, i.e. $Cov(\eta^3, \varepsilon^2) \neq 0$. These shocks may lead mothers to reassess the value they place on the child, thereby, influencing investments in the child's health. If the child experiences health shocks mothers may change their investments in the child's health. For example, mothers may choose to immunize children whose health status places them at greater risk because parents will adjust their behavior to the production of child survival when they observe these.[3]

Third, child immunization and delivery care may be conditioned on family endowment, i.e. $Cov(\eta^2, \mu) \neq 0$ and $Cov(\eta^3, \mu) \neq 0$. Several researchers have addressed $Cov(\eta^1, \mu) \neq 0$. Jeffery E. Harris (1982) points out that the effect of prenatal care on infant mortality is biased when selective timing of care is ignored because a pregnant woman being in frail health is more likely to seek early prenatal medical care than her counterpart whose health is robust; i.e., there is adverse self-selection in the use of prenatal care. Likewise, Panis and Lillard (1994) and Rosenzweig and Schultz (1988, 1983, 1982) argue that women who anticipate a problematic birth or miscarriage have seek out more or earlier prenatal care. Steven L. Gortmaker (1979) raised the possibility of the opposite selection. He argues that a woman with lower stress levels may have better health outcomes and may also get more prenatal care; i.e, there is favorable self-selection in the use of prenatal care.

Rosenzweig and Schultz (1991), in a study of demand for medical care services in the United States, found that ultra-sound and X-ray treatments are less obtained by high-risk women, although high-risk women are more likely to obtain Caesarean section and amniocentesis. Grossman and Joyce (1990) found that, for black women in New York City, the unobserved factors that raise the probability of giving birth are positively related with the unobserved factors that decrease delay in the initiation of prenatal care and increase birth weight. Likewise, child immunization and delivery care may be conditioned on family endowment, either via adverse selection or favorable selection.

Finally, a child's immunization status may be conditioned on the selection of prenatal care and delivery in a modern health facility (i.e. $Cov(\eta^i, \eta^j) \neq 0$) if a mother favorable to prenatal care, conditional on her observable characteristics, is also more likely to obtain delivery care as well as immunization, engaging in complementary behavior.

Given a child's mortality in various biological determinants, the mother's selections influence observed mortality and demand for immunization. Ignoring adverse selection may understate the effect of health care on child survival. Omitting the histories of postnatal stochastic terms may also understate the impact of immunization. On the contrary, ignoring favorable selection may overstate the true effect of health care on child survival. Ignoring complementarity among measured health inputs may overestimate the effect of prenatal care on the demand for immunization. Although ignoring complementarity does not bias the estimated coefficients in the survival production function,[4] its existence between measured inputs may imply the possibility of favorable selection between measured and unmeasured inputs.

Several medical studies try to examine the relation of mothers' psychological factors regarding demand for immunization. But as they point out, a few attitude or belief variables may not capture all the heterogeneity of parents and it is likely that immunization-seeking behavior is influenced by other unobserved factors.[5] This study employs two types of equations as follows, given the correlation among equations. The child survival production function is the first equation and it estimates the effect of immunization on child mortality. In this equation, child mortality is defined as the conditional probability of dying between the first and fourth birthdays among those who survive the first year. This age group was selected because full immunization is recommended for all children by age one and data is collected for the children born in the period 12–48 months before the survey.[6] It is modeled as failure time processes represented by a continuous log hazard of duration equations. The baseline log-hazard function is assumed to be linear with an intercept, i.e. a piecewise Gompertz.[7] The log hazard of child survival production equation at child age t is then given by

$$\ln h(t) = \alpha t + \beta_1 T^1 + \beta_2 T^2 + \beta_3 T^3 + x\gamma + \mu + \xi, \quad (3)$$

where h is the log-hazards of child postnatal mortality, α, β, and γ are parameters, and ξ is an error term.

The conditional likelihood of child survival (L^S) is then given by

$$L^S(\mu) = \begin{cases} S^c = \Gamma(t^c, T, x, \mu) & \text{if the child is still alive at the survey date (c: censored),} \\ S^u = \Gamma(t^s, T, x, \mu) & \text{if the child died between 12 and 48 months} \\ & \text{(u: uncensored).} \end{cases} \quad (4)$$

For the computation of S^u, a monthly window during which the child died is created.

The second type of equation is the reduced form demand functions and it is used to estimate the effects of selected variables on factor demand. I measure a child's immunization status which indicates whether the child are fully immunized, partially immunized, or not immunized at all. Children who have received BCG vaccine, measles vaccine, three doses of DPT vaccine, and three doses of polio vaccine (not counting polio 0) are considered fully immunized. Children who have had one or more vaccinations but are not fully immunized are defined as partially immunized.

Let the underlying response model be described as

$$T^3 = Z_3\delta_3 + \eta^3 + v, \quad (5)$$

where Z_3 includes M, z, and ε . T^3 equals zero if the child is not immunized at all, one if the child is partially immunized, and two if the child is fully immunized. It belongs to the jth category if $c_{m-1} < T^3 < c_m (m = 1, 2)$ where c_s are unknown threshold parameters to be estimated. Assuming that $\eta^3 \sim N(0, \sigma^2_{\eta^3})$, the likelihood for each child can be written as:

$$L^D(\eta^3) = \begin{cases} \Phi[(c_1 - Z_3\delta_3 - \eta^3)/\sigma_{\eta^3}] & \text{if not immunized at all,} \\ \Phi[(c_2 - Z_3\delta_3 - \eta^3)/\sigma_{\eta^3}] - \Phi(c_1 - Z_3\delta_3 - \eta^3)/\sigma_{\eta^3}] & \text{if partially immunized,} \\ 1 - \Phi[(c_2 - Z_3\delta_3 - \eta^3)/\sigma_{\eta^3}] & \text{if fully immunized.} \end{cases} \quad (6)$$

Similarly, demand for prenatal care and delivery care is respectively, modeled as a binary choice model.

The study estimates the model in three ways. By simplifying Equations (1) and (2), define the reduced form, conditional form, and hybrid form as,
Reduced form: $S = \Gamma(T^1, T^2, T^3), T^i = \psi^i(p, M), i = 1, 2, 3$.
Hybrid form: $S = \Gamma(T^1, T^2, T^3, M), T^i = \psi^i(p, M), i = 1, 2, 3$ and,
Conditional form: $S = \Gamma(T^1, T^2, T^3), T^1 = \psi^1(p, M)$,
$T^2 = \psi^2(p, M, T^1), T^3 = \psi^2(p, M, T^1, T^2)$.

First, the reduced form model is estimated using family (mother) random effects. It is a feasible Generalized Least Squares estimates with a weight, $\hat{\Omega}^{-1}$, with $\hat{\Omega} = \hat{\sigma}^2_\xi I + \hat{\sigma}^2_\eta jj'$ where I is a 3×3 (since the maximum number of children is three in the data set) identity matrix, j is a 3×1 vector of ones, and $\hat{\sigma}^2_\xi$ and $\hat{\sigma}^2_\eta$ are respectively, the variance of the child disturbance term and the mother's child-invariant heterogeneity term. The estimator counts for the mother specific heterogeneity in each equation which does not vary across births by the same mother. The family random effects estimates are *only* achieved from the reduced form input demand and production function ignoring any selection between equations (the first specification of Tables 4 and 6). The panel structure is inherently unbalanced because the number of births varies across women. Second, the model is estimated using a hybrid form model. Estimates of technological effects of inputs on health have been thus sometimes obtained from a hybrid function (e.g. Panis and Lillard, 1994) in which variables that do not fit into the category of inputs, such as income or expenditure variable, often appear as determinants. If certain health inputs are omitted, the child mortality specification is essentially a hybrid of a production function and the reduced form demand function. However, if child survival production function is correctly specified, these measures may not have substantial effect on child mortality. Third, the model is estimated using a conditional form model. As addressed earlier, prenatal and delivery care may not only directly lead to greater survival rates of children, but they may affect access to child immunization since experienced mothers with prenatal care may learn about the value of delivery at modern clinics or about the value of child immunization. Conditional form model is estimated by treating both delivery care and prenatal care endogenous in immunization equation. All three models are estimated and their results are compared.

When all inputs are treated as endogenous, the joint marginal likelihood is given by

$$\int_{\mu}\int_{\eta^1}\int_{\eta^2}\int_{\eta^3} f(\mu,\eta^1,\eta^2,\eta^3)\prod L^s(\mu)\prod L^D(\eta^1)\prod L^D(\eta^2)\prod L^D(\eta^3)d\mu d\eta^1 d\eta^2 d\eta^3, \tag{7}$$

where $f(\mu,\eta^1,\eta^2,\eta^3)$ denotes the four dimensional normal density function. In order to exploit efficiencies, this full specification model is estimated jointly based on a Full Information Maximum Likelihood (FIML) method. If all equations are specified in the correct manner, then FIML method will yield consistent estimates. Identification of parameters is discussed in the following section.

3. Data and variables

The 1992–1993 NFHS in India gathered information on a representative sample of 89,777 ever-married women age 13–49 residing in 88,562 households. The survey also collected information on children born to interviewed women in the four years preceding the survey. An advantage of the NFHS is that the data set collected health information for children who died. Several researches examined the determinants of immunization coverage by using only living children because no immunization information was obtained for children who died (e.g. Anne R. Pebley, Noreen Goldman, and German Rodriguez, 1996). The restriction of immunization estimates to living children probably has resulted in overestimate of immunization coverage, which is not a problem of using the NFHS data set. The analysis focuses on children in rural India born 12–48 months preceding the survey.[8] The total number of children belonging to this group is 26,575, among which 542 died. The total number of household is 19,776 and the maximum number of children from the same mother is three.

Three types of questionnaires were used in the NFHS—one for ever-married women within households, one for households, and one for villages. For our analysis, selected variables from the household questionnaire, and the village questionnaire were merged into the individual data file for women of childbearing age. The child data file used in this paper was then created from the augmented individual women data file. Thus, the record for each child includes selected characteristics of the child, the child's mother, the child's father, the mother's household, and the mother's village. The sample design for some states is self-weighting, but in other states certain sectors of the population are over-sampled. It is therefore necessary to use weights to restore the correct proportions. All estimates in this paper make use of weighted numbers at the national level. Details of the sample design are described in the report for the NFHS in India (IIPS, 1995).

Table 1 lists the variables in each model equation, their definitions and their mean. The information on immunization coverage is derived both from vaccination cards, when the mother has one, and from the mother's memory, when she cannot show a card. Each mother was asked whether she had a vaccination card for each child born since January 1988. If a card was available, the interviewer copied the date for each vaccination. If the mother could not produce a vaccination card, she was asked whether the child had received any vaccinations. If any vaccination had been received, the mother was then asked whether the child had received one or more vaccinations against each of the six fatal diseases. For DPT and polio, information was obtained on the number of injections or oral doses given. The prenatal care variable indicates whether a mother received prenatal care in the first trimester and the delivery care variable indicates whether mother had delivery in a modern health facility for the child.

The survival production function is identified by several variables representing household economic status and community characteristics: i.e., *per capita* household expenditure, house quality, a degree of crowding within the household, media exposure, scheduled Caste/tribe, religion, access to health care facility in a village, and all-weather road in a village. Because there are only three endogenous input variables in the production function, the production function is overidentified. Birth spacing, breastfeeding, and birth orders are also included in survival production function as a measure of maternal depletion and child nutrition.[9] These variables are, however, treated exogenous in the analysis in order to avoid additional complication of the model.[10] The order condition is also met for all input demand functions because there are at most two endogenous variables in each conditional demand functions. However, the immunization equation is identified from neither prenatal care nor delivery care because all the exogenous variables in the delivery care and prenatal care equations are also included in the immunization equation. Identification of immunization equation in this paper thus purely relies on functional form assumptions via the non-linearity.[11]

The NFHS data set does not contain information on household income. The study utilizes the 1993 (50th round) NSS in India to project per capita household expenditure. It is projected based on father's occupation (7 categories), education

Table 1. Definitions and mean values of variables.

Variable	Definition (In case of dummy variable value 1 if the specified condition is met, 0 otherwise)	Equation[a] I	II	III	IV	Mean (s.e.)
Full immunization	Child has received BCG, measles, and three doses of DPT and polio vaccines	X				0.306
Partial immunization	Child has had one or more of vaccines, but not fully immunized	X				0.326
Delivery in a modern facility	Mother had delivery in a modern health facility for the child.	X	C			0.160
Prenatal care	Mother received prenatal care in the first trimester	X	C	C		0.141
Mother's education			X	X	X	
Literate, < middle	Mother is literate with less than middle school					0.155
≥ Middle complete	Mother is literate with middle school complete or higher education					0.109
Mother's age	Mother's age at childbirth and its squared	X	X	X	X	23.6 (5.74)
Media exposure	Mother watches television or listens to radio at least once a week or visits a cinema at least once a month		X	X	X	0.384
Birth spacing	Child's birth spacing (months)	X				26.1 (22.3)
Log of per capita household expenditure	Predicted by using 1993 National Sample Survey of India		X	X	X	5.87 (0.245)
Child's sex	Child is a boy	X	X			0.508
Sibling composition		X	X	X	X	
Number of old boys	Number of old male siblings					0.992
Number of old girls	Number of old female siblings					1.077
First child	The child is the first child					0.258
Breast feeding	Child has been breastfed	X				0.982
Muslim	Child lives in a household whose head is Muslim		X	X	X	0.131
Scheduled Caste/Tribe	Household head is scheduled Caste/tribe		X	X	X	0.256
Type of house	Type of house is *pucca*, or *semi-pucca* (quality house)		X	X	X	0.381
Crowding	Number of people per sleeping room		X	X	X	3.66 (2.13)
Sanitary toilet	Child lives in a household that has own or shared flush toilet facility	X	X	X	X	0.054
Safe drinking water	Child lives in a household that uses safe drinking water	X	X	X	X	0.354
Health-care facility	Child lives in a village that has a modern health clinic		X	X	X	0.661

Table 1. Continued.

Variable	Definition (In case of dummy variable value 1 if the specified condition is met, 0 otherwise)	Equation[a]				Mean (s.e.)
		I	II	III	IV	
All-weather road	Child lives in a village that is connected by an all-weather road		X	X	X	0.481
Number of children	Number of chidren age 12–48 months			26,575		

[a] Equation I is child mortality model, II demand for immunization model, III child delivery model, IV demand for prenatal care. Other variables include thresholds and 24 State dummies. C and H means that they are respectively, included in a conditional form and hybrid form model. Based on the weighted sample. Standard errors are in parentheses.

(8 categories), age, age squared, and their residence (24 State dummies). Only father's characteristics are included in the estimation, since the mother's labor is assumed to be endogenous in child health investment decisions. Per capita expenditure is used as a measure of long-run income since it is considered a good proxy for measure of permanent income.[12]

Our theory suggests that mother's demand for immunization is likely to be correlated with birth outcome ($Cov(\eta^{i+k}, \varepsilon^i) \neq 0$). In this context, child's sex plays a role in India where son preference is common. In India, a child's sex is usually not known until the time of delivery. When the gender outcome is revealed at delivery, this affects parents' behavior leading to different treatment of sons and daughters. Although a child's sex is not an input to survival process, I include them in the survival production function as well to consider different chances of survival by gender in India. The child's sibling composition is included in all models to capture the effect of resource competition. Because higher-order births are born into families that already have a number of children who compete for resources and parental care, these variables are expected to play an important role in parents' demand for health input. Furthermore, the resource competition may depend on the sex composition of the surviving old siblings. Thus, the number of older surviving male and female siblings is included separately in the models.

Health care costs are difficult to measure and often do not vary markedly across mothers in most of the environments from which survey data are derived. Reduced form estimates of the effects of variation in prices on measures of human capital investments are thus absent from most previous literature. To proxy for the cost of access to general health-care facilities, availability of an all-weather road connecting the village to the outside and a health-care facility in the village are included in all reduced form demand equations. There are several types of health-care facilities in India. I include a measure of the availability of the following kinds of facilities in the mother's village: Primary Health Centre, sub-centre, government hospital, private hospital, dispensary/clinic, or NGO family planning/health clinic.

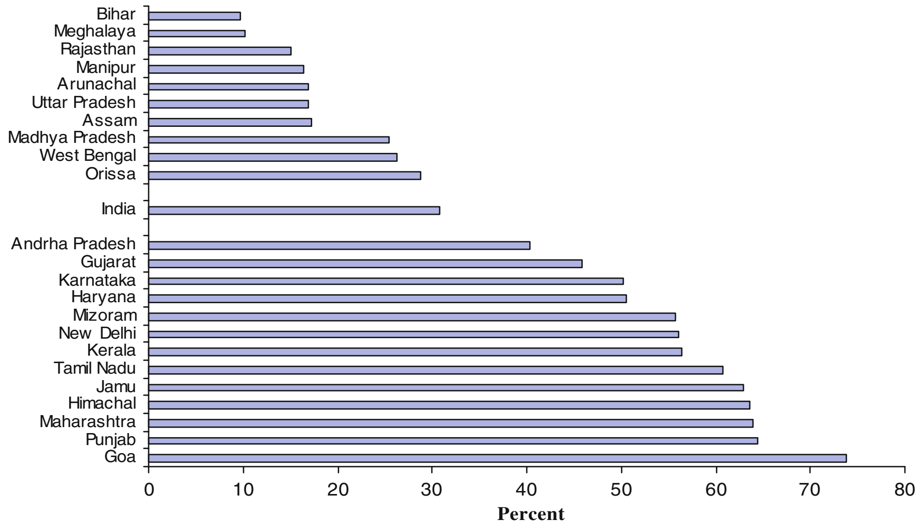

Figure 1. Percentage of children who received all vaccinations by State.

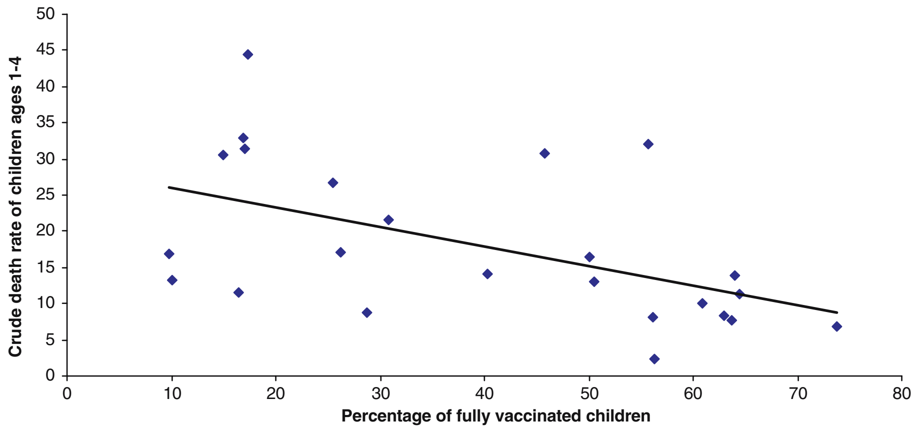

Figure 2. Relationship between percentage of fully vaccinated children and child mortality rate by State.

There is a considerable interstate variation in the coverage rate for different vaccinations and child mortality rate. Figure 1 shows the percentage of children who are fully vaccinated by State; it ranges from 10 percent in Bihar to 74 percent in Goa. Generally, the western and southern states do relatively well with respect to full coverage immunization, whereas the northeastern and central states have a poor vaccination performance as well as lower child survival. There is also a negative relationship between the immunization rate and crude death rate of children (Figure 2). In order to consider the considerable interstate variation which may not be captured by the other independent variables, the paper includes these 24 State dummy variables in all models as controls. Other exogenous variables such as sanitary toilet and safe drinking water are included in all models as controls.

Table 2 presents the percentage of children age 12–48 months who received each vaccine at any time before the interview by source of information and selected demographic and socioeconomic characteristics. I use information from both vac-

Table 2. Percentage of children vaccinated and crude death rate by vaccination type.

	Percentage vaccinated					
Selected variables	BCG	Polio 3	DPT 3	Measles	All[a]	None[c]
Total (percentage)	54.8	47.0	45.0	38.1	30.6	36.8
Source of information						
Vaccination card	87.5	82.9	82.5	65.3	58.2	..
Mother's report	46.8	38.2	35.9	31.4	23.8	45.8
Mother's education						
Illiterate	46.9	38.4	36.4	30.1	23.0	44.4
Literate < Middle school complete	70.2	63.7	62.3	52.3	44.4	20.8
Middle school/above	86.1	81.0	79.3	71.3	62.4	7.9
Scheduled caste/tribe						
Yes	49.1	39.3	38.0	32.6	25.0	42.5
No	56.7	49.0	47.5	39.9	32.5	34.8
Child's sex						
Boy	57.1	49.0	47.0	39.9	31.9	33.9
Girl	52.3	44.9	43.0	36.1	29.3	39.8
Child's sibling composition						
Have old male siblings	49.5	41.3	39.4	32.4	25.5	42.0
Have old female siblings	49.9	41.8	40.0	33.3	26.4	41.6
No older siblings	63.1	56.3	54.3	47.1	38.7	28.4
Religion						
Hindu	56.9	49.0	47.2	39.9	32.2	34.8
Muslim	40.5	33.6	31.0	26.0	19.7	50.3
Health-care facilities						
Yes	59.1	51.4	49.8	41.9	34.2	32.2
No	46.3	38.3	35.8	30.5	23.5	45.8
Prenatal care						
Yes (in the first trimester)	79.3	74.4	72.0	63.3	53.9	13.3
No (no prenatal care)	40.7	32.3	30.3	25.0	18.6	51.1
Delivery in a modern facility						
Yes	83.7	77.2	75.7	66.2	57.5	10.0
No	49.3	41.2	39.2	32.7	25.4	41.9
Crude death rate (per 1000)						
Vaccinated	10.9	9.1	9.4	8.0	7.5[a]	–
Not vaccinated	37.7	35.3	34.2	32.2	14.2[b]	43.7[c]

Based on the weighted sample.
The number of observations is 26,575.
[a] Fully vaccinated.
[b] Partially vaccinated.
[c] No vaccination.

cination cards and mother's memory. The information does not provide the date of vaccination and it might have higher percentage of children who did not meet the criteria recommended by WHO. However, Noreen Goldman and Anne R. Pebley (1994) demonstrate that inclusion of maternal recall data improves the accuracy of estimates of immunization coverage even though it is subject to recall error. The coverage rate, defined in this way, varies by type of vaccine. Only 31 percent of children aged 12–48 months are fully vaccinated, and 37 percent have not received any vaccine.[13]

Thirty-two percent of children have had one or more vaccinations but are not completely vaccinated, i.e. partially immunized. The analysis of partial immunization provides some insight into the causes of the low coverage rate for full immunization. According to the NFHS, an exceptionally low rate of measles vaccination and high dropout rates during the three-part DPT and polio vaccination series are the main causes of the low rate of full immunization (Appendix A). Thirteen percent of children ages 12–48 months failed to reach full immunization because they missed only one vaccination. Among the 13 percent who missed only one vaccination, 70 percent missed measles vaccination. The dropout rates between the first and third doses of DPT and polio vaccination are 24 and 21 percent, respectively. This may reflect the time-dependency problem in vaccination. The measles vaccination rate is particularly low in part because it is given to a baby much later stage of life (9 months) than the other vaccines are. Since the hazard of mortality is highest at the early stage of life, a mother has a strong incentive to have her child vaccinated. However, the incentive might be much weaker after 9 months because a child might already have had all vaccination except measles and survived 9 months. If measles vaccines are more expensive for mothers to get, it will exacerbate the problem. The outcome of this incomplete immunization will be discussed later.

Immunization coverage increases with mother's education. Hindu children are more likely to be vaccinated than Muslim children are. Children with elder siblings tend to have lower vaccination rates. Coverage is also higher for boys than for girls. Mortality rates are much higher for the group who is not immunized. The crude death rate of fully vaccinated children ages 12–48 months is 7.5 per 1000 children while it is 43.7 for those who are not vaccinated. The crude death rate of partially vaccinated children is 14.2.

4. Estimation results

4.1. Mother's compensatory and complementary behavior

Table 3 presents estimation results of the unobserved heterogeneity structure. This corresponds to the full specification of the model (model 5 in Table 4), where prenatal care, place of delivery, and immunization status are all considered endogenous. The diagonal elements are standard deviations of the heterogeneity, whereas the off-diagonal elements are correlation coefficients among heterogeneity. The result suggests that there are two types of self-selections of a mother.

Table 3. Heterogeneity structure estimates.

	μ	η^3	η^2	η^1
Child mortality (μ)	1.168 *** (0.182)	–	–	–
Immunization (η^3)	0.478 *** (0.067)	1.440*** (0.095)	–	–
Delivery in a modern facility (η^2)	0.438 *** (0.076)	0.255*** (0.019)	1.762*** (0.113)	–
Prenatal care (η^1)	0.526 *** (0.139)	0.244*** (0.020)	0.363*** (0.025)	1.423*** (0.040)

Standard errors are in parentheses. Diagonal elements are standard deviation, and off-diagonal elements are correlation coefficients. Estimates of the heterogeneity structure corresponding to the full specification (column (5) in Table 4).
*** indicates significance from zero at 1 percent.

The first type of self-selection is the correlation between survival production function and demand for health care inputs. The correlation coefficient of the mother's heterogeneity between the survival production function and immunization function ($\rho_{\mu\eta^3}$) is 0.478 and statistically significant at one percent significance level. The correlation coefficients between the survival production function and the demand for delivery care ($\rho_{\mu\eta^2}$) and demand for prenatal care ($\rho_{\mu\eta^1}$) is 0.438 and 0.526, respectively, and they are statistically significant as well. The significant and positive correlation coefficients between the survival production function and all three reduced-form demand functions implies that women with a relatively higher risk of losing their child are more likely to seek prenatal care, delivery care at a modern facility, and immunization. That is, there is adverse self-selection in the use of prenatal care. So mothers could be said to compensate for inherently weak endowment, engaging in remedial behavior.

The second type of selection is related with mother's complementary behavior. The correlation coefficients between three reduced-form demand functions are all positive ($\rho_{\eta^3\eta^2} = 0.255, \rho_{\eta^3\eta^1} = 0.244, \rho_{\eta^2\eta^1} = 0.363$) and are statistically significant at one percent significance level, suggesting that women who obtain one health care are more likely to obtain another health care. This means that women engage in complementary behavior by reinforcing investment when they choose among different health inputs.

Ignoring the selection identified above will bias the estimation results. For example, ignoring the adverse selection will understate the estimated impact of immunization on child survival. Ignoring mother's complementary behavior may overstate the impact of delivery care and prenatal care on conditional form of immunization equation. The evidence of complementarity among measured inputs also suggests that there might be favorable selection between measured and unmeasured inputs as well, although the adverse selection seems to be dominant.

4.2. Effect of the mother's selection on child mortality

Table 4 shows how important it is to account for the adverse selection. All columns in the table present the results of reduced form input demand models.

That is, none of the demand for health care models includes other health care, ignoring the indirect effect of health care on increasing the access of the following care. Column 1 presents family random effects estimator which only considers the effect of mother's random effects across children. In column 1, all health care inputs are treated exogenous. The results indicate that immunization has a very large and significant beneficial effect on child mortality. The impact of full immunization is −1.635, implying that full vaccination decreases the risk by 80 percent ($1-e^{\beta}$).[14] This means that the risk of vaccinated children is about one-fifth of that of non-vaccinated children. The impact of partial immunization is much smaller than that of full immunization, (−1.008, 64 percent), suggesting that

Table 4. Estimates of child mortality model (Log-hazard model, reduced form input model).

	(1) Family RE only	(2) Endogenous immunization	(3) Endogenous delivery care	(4) Endogenous parental care	(5) All inputs are endogenous
Immunization					
Full	−1.6348 ***	−2.8944 ***	−1.5693 ***	−1.5809 ***	−2.4687 ***
	(0.1727)	(0.2870)	(0.1706)	(0.1703)	(0.2520)
Partial	−1.0081 ***	−1.6140 ***	−0.9765 ***	−0.9848 ***	−1.4308 ***
	(0.1250)	(0.1692)	(0.1230)	(0.1232)	(0.1542)
Delivery in a modern clinic	−0.3674 *	−0.3095	−1.2391 ***	−0.3244	−0.8573***
	(0.2082)	(0.2087)	(0.2888)	(0.2064)	(0.2601)
Prenatal care	0.0756	0.1108	0.1018	−0.8222 **	−0.6286 **
	(0.1860)	(0.1871)	(0.1840)	(0.3417)	(0.3153)
Breast feeding	−1.4014 ***	−1.3824 ***	−1.4003 ***	−1.3862 ***	−1.3713 ***
	(0.2183)	(0.2086)	(0.2067)	(0.2057)	(0.1975)
Birth spacing	−0.0207 ***	−0.0216 ***	−0.0208 ***	−0.0210 ***	−0.0218 ***
	(0.0033)	(0.0034)	(0.0033)	(0.0033)	(0.0033)
Clean water	−0.2240 **	−0.1670	−0.1869 *	−0.2080 *	−0.1519
	(0.1090)	(0.1089)	(0.1077)	(0.1071)	(0.1066)
Sanitary toilet	−0.4654	−0.2548	−0.2744	−0.2872	−0.0639
	(0.3770)	(0.3789)	(0.3753)	(0.3752)	(0.3766)
Boy	−0.4409 ***	−0.3780 ***	−0.4340 ***	−0.4331 ***	−0.3849 ***
	(0.0960)	(0.0967)	(0.0947)	(0.0945)	(0.0941)
First child	−0.8714 ***	−0.8904 ***	−0.8068 ***	−0.8466 ***	−0.8279 ***
	(0.1874)	(0.1879)	(0.1853)	(0.1853)	(0.1843)
Sibling composition					
Old boy	0.0842 *	0.0432	0.0599	0.0648	0.0272
	(0.0502)	(0.0505)	(0.0493)	(0.0493)	(0.0491)
Old girl	−0.0149	−0.0474	−0.0382	−0.0322	−0.0635
	(0.0531)	(0.0532)	(0.0524)	(0.0522)	(0.0519)
Mother's age					
At birth	0.0139	0.0321	0.0351	0.0263	0.0492
	(0.0596)	(0.0592)	(0.0583)	(0.0584)	(0.0577)
Squared	−0.0004	−0.0006	−0.0006	−0.0005	−0.0008
	(0.0011)	(0.0011)	(0.0011)	(0.0011)	(0.0011)

Standard errors in parentheses. Other variables include 24 State dummy variables.
The number of observations is 26,575.
*, **, *** indicate significance from zero at 10 percent, 5 percent and 1 percent, respectively.

skipping one or two vaccinations substantially reduces the beneficial effect of immunization. The results are not surprising at all, because the crude death rate of non-vaccinated children is about six times as high as that of fully vaccinated children and three times as high as that of partially immunized children (see Table 2). Delivery in a modern health clinic also has a significant beneficial effect on child survival (−0.367, 31 percent), but the impact of prenatal care on child mortality is insignificant.

In column 2, the reduced form immunization demand model and the child survival production function are estimated jointly, considering the potential correlation between two equations. The mother's behavior during pregnancy and at birth is still treated exogenous to consider only the effect of adverse selection on demand for immunization. When the selection in demand for immunization is considered, the effect of immunization becomes much larger (−1.614 (80 percent) for partial immunization and −2.919 (95 percent) for full immunization), suggesting that ignoring the adverse selection between the mother's frailty and demand for child immunization substantially underestimates the beneficial effect of immunization. Furthermore, the beneficial effect of delivery care on child mortality becomes no longer statistically significant. Column 3 and 4, respectively, present the results when the selection in delivery care and prenatal care is considered. The pattern of bias is very similar to column 2. When the selection in a modern health clinic and prenatal care are respectively, considered in each model, their beneficial effects on child mortality become very large (−1.239 in column 3 and −0.822 in column 4) and significant at one percent significance level. Thus, ignoring the adverse selection between a mother's frailty and health inputs substantially understate the true impact of child health care on child survival. Column 5 presents results when all four models are jointly estimated. The results are qualitatively similar to the pattern in columns 2–4 in which selection in each health care is considered, respectively. The estimated coefficients of immunization status, delivery care, and prenatal care are all substantially lower than those of column 1.

Table 4 also summarizes the effect of other control variables. In all models, birth spacing, sex of child, and the indicator of first child have a statistically significant influence on child survival. Use of safe drinking water also has a significant effect on some regressions. The coefficient on whether a child is breastfed is also significant. However, the result should be interpreted with caution since the practice of breastfeeding is almost universal in India and it is treated exogenous (see footnotes 9 and 10). The other variables have no significant impact on child mortality, suggesting that they operate mostly through demand for health inputs.

The child survival production function is re-estimated including per capita household expenditure. The result of this hybrid form model is reported in column 2 of Table 5. For comparison, the result of the full specification model (column 5 of Table 4) is reported again in column 1 of Table 5. The coefficient of the log of per capita household expenditure variable is not significant at all. The insignificant income effect provides support for the hypothesis that the child

Table 5. Sensitivity analysis of the child mortality model.

Model	(1) Reduced form (All endogenous inputs = (5) of Table 4)	(2) Hybrid form ((1) + per capita HH expenditure)	(3) Conditional form (All endogenous inputs & conditional form input
Immunization			
Full	−2.4687 ***	−2.4900 ***	−2.4487 ***
	(0.2520)	(0.2624)	(0.2520)
Partial	−1.4308 ***	−1.4411 ***	−1.4228 ***
	(0.1542)	(0.1585)	(0.1539)
Delivery in a Modern clinic	−0.8573 ***	−0.8146 ***	−0.8650 ***
	(0.2601)	(0.2634)	(0.2603)
Prenatal care	−0.6286 **	−0.6311 **	−0.6593 **
	(0.3153)	(0.3206)	(0.3207)
Per capita Household expenditure	..	0.0249	..
		(0.2880)	
Breast feeding	−1.3713 ***	−1.3696 ***	−1.3684 ***
	(0.1975)	(0.1960)	(0.1965)
Birth spacing	−0.0218 ***	−0.0219 ***	−0.0218 ***
	(0.0033)	(0.0033)	(0.0033)
Clean water	−0.1519	−0.1797 *	−0.1522
	(0.1066)	(0.1059)	(0.1065)
Sanitary toilet	−0.0639	−0.1976	−0.0611
	(0.3766)	(0.3731)	(0.3763)
Boy	−0.3849 ***	−0.3817 ***	−0.3842 ***
	(0.0941)	(0.0940)	(0.0940)
First child	−0.8279 ***	−0.8331 ***	−0.8274 ***
	(0.1843)	(0.1839)	(0.1840)
Sibling composition			
Old boy	0.0272	0.0252	0.0268
	(0.0491)	(0.0490)	(0.0489)
Old girl	−0.0635	−0.0638	−0.0637
	(0.0519)	(0.0517)	(0.0518)
Mother's age			
At birth	0.0492	0.0511	0.0495
	(0.0577)	(0.0576)	(0.0576)
Squared	−0.0008	−0.0008	−0.0008
	(0.0011)	(0.0011)	(0.0011)

Standard errors in parentheses. Other variables include 24 State dummy variables.
The number of observations is 26,575.
*, **, *** indicate significance from zero at 10 percent, 5 percent and 1 percent, respectively.

mortality specification captures most important input factors and other control variables and the coefficients of these variables may be interpreted as survival production technology coefficients.

Column 3 of the table presents results when input demand equations are estimated as conditional form model. That is, the prenatal care variable is included in the delivery care immunization coverage model, and both prenatal care and delivery care variables are included in the demand for immunization model. Again, all four models are estimated jointly. The result is quite similar to column 5 of Table 4, suggesting that the change in coefficients of Table 5 should be due to mother's adverse self-selection and it is not a side effect of our choice of reduced form model. Once mother's adverse selection is considered, the indirect role of health care in triggering additional child health input no longer matters for child survival. This issue will be discussed more in detail in the following section.

4.3. Results of the immunization coverage model

Table 6 reports the ordered-probit estimation results of the immunization coverage model. Two estimated threshold parameters are significant at one-percent level. Column 1 corresponds to column 1 of Table 4 in which all equations are estimated separately. Column 2 corresponds to column 5 of Table 4 where all equations are estimated jointly. Column 3 is a conditional form of immunization coverage model in which both prenatal care and delivery care variables are included, but regarded as exogenous variables. Column 4 corresponds to column 3 of Table 5 where prenatal care and delivery care variables are treated endogenous in the conditional form demand model. The corresponding estimation results for the delivery care and prenatal care models are also presented in Appendixes 2 and 3, respectively.

Most variables have the expected sign and they are significant. When the two types of selection are considered, all estimated coefficients move away from zero, suggesting that ignoring the two types of selection substantially underestimates the effect of control variables (column 1 versus 2).[15] The most interesting feature of Table 6 is the dramatic change in the coefficients of prenatal care and delivery care when they are estimated jointly. The coefficient of prenatal care variable changes from 0.374 in column 3 to −0.182 in column 5. Likewise, the coefficient of prenatal care changes from 0.463 in column 3 to 0.079 in column 4 and it is not significant any more. The result for delivery in a modern facility model in Appendix B is qualitatively same. That is, the indirect role of prenatal care in triggering access to the delivery care disappears when all models are estimated jointly. To summarize, when the mother's complementary behavior among measured inputs are considered, the indirect role of health care in triggering additional child health input disappears. So it can be said a mother who is favorable to prenatal care, conditional on her observable characteristics, is also more likely to obtain delivery care as well as immunization due to self-selection and this substitutes the triggering role of prenatal health care.

The mother's level of education also had a substantial impact on child immunization status. Since the effect of per capita household expenditure and other family economic status are controlled for, it also reflects the influence of accessibility to information, mothers' preference, and other quality of the home environment on immunization. This is consistent with the notion that education

Table 6. Estimates of immunization coverage model (Ordered Probit).

	(1) Family RE only	(2) Reduced form All endogenous inputs	(3) Conditional form All enxogenous inputs	(4) Conditional form All endogenous inputs
Prenatal care	..	..	0.3744 ***	−0.1817 **
			(0.0399)	(0.0907)
Delivery in a modern clinic	..	..	0.4631 ***	0.0786
			(0.0427)	(0.1082)
Per capita HH expenditure	1.0144 ***	1.0670 ***	0.9060 ***	1.0835 ***
	(0.0744)	(0.0805)	(0.0745)	(0.0822)
Mother's education				
Literate	0.4541 ***	0.4771 ***	0.3957 ***	0.4828 ***
	(0.0406)	(0.0438)	(0.0405)	(0.0449)
Mid. or above	0.9018 ***	0.9428 ***	0.7500 ***	0.9624 ***
	(0.0566)	(0.0621)	(0.0568)	(0.0669)
Muslim	−0.5044 ***	−0.5480 ***	−0.4760 ***	−0.5467 ***
	(0.0413)	(0.0449)	(0.0412)	(0.0454)
Scheduled caste/tribe	−0.1259 ***	−0.1433 ***	−0.0987 ***	−0.1463 ***
	(0.0314)	(0.0338)	(0.0315)	(0.0341)
Good house	0.1715 ***	0.1757 ***	0.1463 ***	0.1762 ***
	(0.0311)	(0.0335)	(0.0311)	(0.0338)
Crowding	−0.1077 ***	−0.1130 ***	−0.1052 ***	−0.1131 ***
	(0.0279)	(0.0300)	(0.0279)	(0.0301)
Clinics	0.1340 ***	0.1467 ***	0.1382 ***	0.1485 ***
	(0.0295)	(0.0317)	(0.0295)	(0.0318)
Road	0.1356 ***	0.1477 ***	0.1207 ***	0.1467 ***
	(0.0292)	(0.0314)	(0.0291)	(0.0316)
Clean water	0.1065 ***	0.1104 ***	0.1013 ***	0.1083 ***
	(0.0299)	(0.0322)	(0.0298)	(0.0323)
Sanitary toilet	0.2513 ***	0.2550 ***	0.1537 **	0.2622 ***
	(0.0708)	(0.0778)	(0.0708)	(0.0794)
Boy	0.2481 ***	0.2623 ***	0.2480 ***	0.2630 ***
	(0.0242)	(0.0255)	(0.0242)	(0.0255)
First child	0.0701 *	0.0713 *	0.0154	0.0713 *
	(0.0369)	(0.0387)	(0.0370)	(0.0397)
Sibling composition				
Old boy	−0.1310 ***	−0.1363 ***	−0.1183 ***	−0.1371 ***
	(0.0142)	(0.0153)	(0.0143)	(0.0155)
Old girl	−0.0902 ***	−0.0936 ***	−0.0783 ***	−0.0944 ***
	(0.0134)	(0.0143)	(0.0134)	(0.0145)
Media exposure	0.3562 ***	0.3689 ***	0.3283 ***	0.3736 ***
	(0.0307)	(0.0331)	(0.0307)	(0.0335)
Mother's age				
At birth	0.0548 ***	0.0595 ***	0.0428 ***	0.0598 ***
	(0.0161)	(0.0173)	(0.0161)	(0.0174)
Squared	−0.0007 **	−0.0008 **	−0.0006 *	−0.0008 **
	(0.0003)	(0.0003)	(0.0003)	(0.0003)

Standard errors in parentheses; other variables include 24 State dummy variables.
The number of observations is 26,575.
*, **, *** indicate significance from zero at 10 percent, 5 percent and 1 percent, respectively.

provides a mother with skills in acquiring and decoding new information, and thus effectively lowers the cost of using more information about new health techniques. Another possible explanation is that more highly educated mother desire healthier child and will be able to provide a home environment that is more conducive to better health. The results also show that a mother who watches television or listens to radio at least once a week is more likely to have her child vaccinated, suggesting that mothers who are exposed to mass media are more likely to have access to information on child health care. I also found that mother's age at child's birth has a significantly positive but nonlinear effect on immunization coverage.

The results also reveal the effect of child characteristics on immunization. Boys have substantially higher vaccination rates than girls, reflecting the strong preference for sons that exists in India. The findings also illustrate the favored treatment of first-born children. Given controls for mother's and child's characteristics, results show that all economic status related variables have significant effects on immunization coverage. Per capita household expenditure has the expected sign and it is highly significant. The coverage is higher for children living in a good quality house and less crowded house.

As expected, the results show that the connection with an all-weather road in local areas and the availability of safe drinking water and sanitary toilet have significantly positive effects on child's immunization. However, availability of clinics has unexpected sign and it is insignificant. The estimate of this variable assumes that no correlation exists between the variables and unobserved component in the outcome. Because immunization programs may be placed using criteria that are related to the outcomes being studied (i.e., non-random program placement) this condition is often violated. Clinics in rural India might be first placed where immunization rate is low and mortality rate is high. Treatment of this potential problem is not addressed here.

5. Summary

Despite considerable gains in immunization coverage over the last few decades, at least two million children still die from vaccine-preventable diseases, including more than a million from measles, and close to 0.4 million from pertussis (whooping cough) (WHO, 1998). In India, immunization coverage is still very low in many regions, a matter of considerable concern to their Government.

By using a family health survey data set of India, this paper estimates the demand for immunization and the effect of immunization coverage on the probability of child survival. For this purpose, a household dynamic production model is constructed in which immunization enters as a postnatal input. Careful attention is paid to addressing issues of potential correlation among immunization status, place of delivery, prenatal care, and survival technology.

The results from the child mortality model indicate that vaccinating children has a very large effect on child mortality. However, the impact of partial immunization is much smaller than that of full immunization, which suggests that partial immunization, due to either dropout or missing vaccinations, substantially reduces the beneficial effect of immunization.

Results also suggest that a mother who perceives her child faces a risk of higher likelihood of death compensates for their beliefs in a beneficial way. Consequently, estimations that ignore this selection underestimate the impact of immunization on child survival. Mothers also engage in complementary behavior by reinforcing investment when they choose among health inputs. Estimations that ignore this selection substantially overstate the impact of prenatal care and delivery care on demand for immunization. The evidence for complementarity among measured inputs also implies that there might be favorable selection between measured and unmeasured inputs, although the adverse selection seems dominant.

The results also indicate that being boys have a significant and positive effect on the likelihood of receiving immunization. That leads us to wonder whether selection differ across gender. Although this is an interesting question, it is left for a future study.

Appendix A. Percentage of children who failed to reach full immunization

Table A.1. Percentage of children who missed only one vaccination.

	Missed BCG only	Missed DPT only	Missed Polio only	Missed Measles only	Number of children
Sex of child					
Male	1.4	1.8	1.0	9.5	13,512
Female	0.7	1.6	0.8	8.9	13,036
Total	1.2	1.9	0.9	9.2	26,575

Table A.2. Dropout rate (%) for DPT and polio vaccination.

	Dropout rate for DPT			Dropout rate for polio		
	Between dose I and II	Between dose II and III	Between dose I and III	Between dose I and II	Between dose II and III	Between dose I and III
Sex of child						
Male	11.1	14.3	23.8	8.9	14.1	21.8
Female	11.5	13.8	23.7	8.8	13.2	20.8
Total	11.3	14.1	23.8	8.9	13.7	21.3

Percentages are based on weighted sample.

Appendix B. Estimates of demand for delivery in a modern facility.

	(1) Family RE only	(2) Reduced form (All endogenous inputs)	(3) Conditional form (All exogenous inputs)	(4) Conditional form (All endogenous inputs)
Prenatal care	..	..	0.7428 ***	−0.0869
			(0.0542)	(0.1419)
Per capita HH expenditure	1.3496 ***	1.4961 ***	1.1849 ***	1.5150 ***
	(0.1293)	(0.1562)	(0.1272)	(0.1604)
Mother's education				
Literate	0.5877 ***	0.6815 ***	0.5181 ***	0.6911 ***
	(0.0579)	(0.0716)	(0.0573)	(0.0732)
Mid. or above	1.0772 ***	1.2470 ***	0.9295 ***	1.2667 ***
	(0.0773)	(0.1008)	(0.0760)	(0.1062)
Muslim	−0.5281 ***	−0.5977 ***	−0.5218 ***	−0.5998 ***
	(0.0754)	(0.0880)	(0.0747)	(0.0885)
Scheduled caste /tribe	−0.4183 ***	−0.4747 ***	−0.3874 ***	−0.4795 ***
	(0.0590)	(0.0688)	(0.0584)	(0.0693)
Good house	0.2973 ***	0.3388 ***	0.2817 ***	0.3434 ***
	(0.0491)	(0.0577)	(0.0486)	(0.0581)
Crowding	−0.0848 *	−0.0892 *	−0.0776 *	−0.0905 *
	(0.0453)	(0.0520)	(0.0448)	(0.0523)
Clinics	−0.0934 *	−0.0984 *	−0.0916 *	−0.0990 *
	(0.0510)	(0.0584)	(0.0504)	(0.0587)
Road	0.2948 ***	0.3434 ***	0.2841 ***	0.3446 ***
	(0.0486)	(0.0567)	(0.0481)	(0.0570)
Clean water	0.1269 ***	0.1461 ***	0.1205 ***	0.1463 ***
	(0.0473)	(0.0543)	(0.0468)	(0.0546)
Toilet	0.6310 ***	0.7013 ***	0.5534 ***	0.7124 ***
	(0.0904)	(0.1065)	(0.0894)	(0.1083)
First child	0.6062 ***	0.6849 ***	0.5742 ***	0.6906 ***
	(0.0603)	(0.0699)	(0.0599)	(0.0704)
Sibling composition				
Old boy	−0.2477 ***	−0.2684 ***	−0.2310 ***	−0.2710 ***
	(0.0288)	(0.0338)	(0.0285)	(0.0341)
Old girl	−0.2157 ***	−0.2278 ***	−0.1958 ***	−0.2307 ***
	(0.0261)	(0.0301)	(0.0257)	(0.0305)
Media exposure	0.2769 ***	0.3047 ***	0.2408 ***	0.3097 ***
	(0.0481)	(0.0565)	(0.0477)	(0.0573)
Mother's age				
At birth	0.1514 ***	0.1689 ***	0.1442 ***	0.1699 ***
	(0.0298)	(0.0338)	(0.0291)	(0.0340)
Squared	−0.0017 ***	−0.0019 ***	−0.0016 ***	−0.0019 ***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)

Standard errors in parentheses; other variables include 24 State dummy variables.
The number of observations is 26,575.
*, **, *** indicate significance from zero at 10 percent, 5 percent and 1 percent, respectively.

Appendix C. Estimates of demand for prenatal care model.

	(1) Family RE only	(2) Reduced form (All endogenous inputs)	(3) Conditional form (All endogenous inputs)
Per capita HH expenditure	1.1905 ***	1.2406 ***	1.2395 ***
	(0.1127)	(0.1241)	(0.1242)
Mother's education			
Literate	0.4746 ***	0.5312 ***	0.5356 ***
	(0.0509)	(0.0587)	(0.0590)
Mid. or above	0.9690 ***	1.0531 ***	1.0607 ***
	(0.0695)	(0.0822)	(0.0827)
Muslim	−0.0782	−0.0684	−0.0681
	(0.0624)	(0.0658)	(0.0659)
Scheduled caste/tribe	−0.2763 ***	−0.3032 ***	−0.3036 ***
	(0.0512)	(0.0550)	(0.0551)
Good house	0.1642 ***	0.1756 ***	0.1759 ***
	(0.0448)	(0.0482)	(0.0483)
Crowding	−0.0135	−0.0040	−0.0035
	(0.0408)	(0.0435)	(0.0436)
Clinics	0.0526	0.0660	0.0694
	(0.0456)	(0.0486)	(0.0486)
Road	0.0615	0.0703	0.0711
	(0.0430)	(0.0458)	(0.0458)
Clean water	0.0434	0.0427	0.0434
	(0.0428)	(0.0457)	(0.0458)
Sanitary toilet	0.4172 ***	0.4345 ***	0.4365 ***
	(0.0833)	(0.0881)	(0.0882)
First child	0.2532 ***	0.2828 ***	0.2846 ***
	(0.0541)	(0.0574)	(0.0574)
Sibling composition			
Old boy	−0.1144 ***	−0.1114 ***	−0.1101 ***
	(0.0241)	(0.0254)	(0.0255)
Old girl	−0.1257 ***	−0.1203 ***	−0.1184 ***
	(0.0224)	(0.0238)	(0.0238)
Media exposure	0.2880 ***	0.3066 ***	0.3071 ***
	(0.0435)	(0.0480)	(0.0482)
Mother's age			
At birth	0.0547 **	0.0558 **	0.0559 **
	(0.0251)	(0.0264)	(0.0264)
Squared	−0.0006	−0.0006	−0.0006
	(0.0005)	(0.0005)	(0.0005)

Standard errors in parentheses; other variables include 24 State dummy variables.
The number of observations is 26,575.
*, **, *** indicate significance from zero at 10 percent, 5 percent and 1 percent, respectively.

Notes

1. As part of the National Health Policy, the Expanded Programme on Immunization (EPI) was introduced in 1978 with the objective of providing free vaccination services to all eligible children and expectant mothers. In order to step up the pace of immunization, the Universal Immunization Programme (UIP) was introduced in 1985–1986 and is being implemented through the existing network of the primary health-care system, including Primary Health Centres (PHCs), sub-centres and referral centres called Community Health Centres. See WHO (1986) for details.
2. For notational convenience, subscripts for child and mother are suppressed.
3. There is also an issue of heterogeneity in the endowment of children born *within* the family. Although this is potentially an important issue, little evidence exists how health inputs are allocated across family members as a function of their inherent endowments. There is a special case in which prenatal inputs for the prior-born children are used as instruments for the difference in prenatal inputs between the later- and prior-born (Rosenzweig and Wolpin, 1988). But one could argue that the lagged instrumental method may perform poorly in part due to the validity of instruments. This is especially true for postnatal care, where, unlike prenatal health input, qualities of child are already known by parents when family decisions about postnatal inputs are made. In this paper I only consider the effects of gender and sibling composition of a child.
4. Consider a production function with two endogenous explanatory variables $y = \beta_1 x_1 + \beta_2 x_2 + \mu + \xi$, where μ is correlated with both explanatory variables and ξ is an error term. Then the estimated coefficient for one variable, x_1, is $\hat{\beta}_1 = E(x_1' M_2 x_1)^{-1}(x_1' M_2 y)$, where $M_2 = (I - x_2(x_2' x_2)^{-1} x_2')$. The expected value of the estimated coefficient is then $E(\hat{\beta}_1) = E(x_1' M_2 x_1)^{-1}(x_1' M_2)(x_1\beta_1 + x_2\beta_2 + \mu + \xi)$ $= \beta_1 + E(x_1' M_2 x_1)^{-1}\ (x_1' M_2 \mu)$. Because $E(x_1' M_2 x_1)^{-1}(x_1' M_2 \mu) = E(x_1' M_2 x_1)^{-1}(x_1' \mu) + E(x_1' M_2 x_1)^{-1}$ $(x_1' x_2 (x_2' x_2)^{-1} x_2' \mu)$, the estimated coefficients are still consistent as long as $E(x_1' \mu) = 0$ and $E(x_2' \mu) = 0$.
5. See Donna Strobino et al. (1996) for a review.
6. The usual truncation problem arises whenever the input is defined to depend on the duration of life or it is dependent on the achievement of a given age. For example, immunizations given after some age is reached would be truncated by death prior to the immunization age thus be spuriously related to life expectancy. However, this is unlikely a problem here since the data is restricted to the children born in the period 12–48 months before the survey, and the majority of children (among those who have vaccination card) vaccinated in the NFHS met the criteria by WHO.
7. A more flexible base-line hazard form is also examined (e.g. different slopes at user-selected nodes). However, the pattern of baseline log hazard function was almost unchanged.
8. It only focuses on rural India in part due to the lack of information on some variables in urban area. For example, village information such as availability of clinics or access to road was not collected in the urban area.
9. The NFHS does not contain detailed information on months of breastfeeding. Furthermore, although the NFHS contains information on breastfeeding with some supplementation, I could not use this information because there have not been any dead children who have had breastfeeding with some supplementation.
10. These variables are often thought of as endogenous in the literature (e.g. Albino Barrera, 1990; Rosenzweig and Wolpin, 1988). However, the use of survey data to estimate the impact of these variables on the risk of child mortality entails serious inferential problems as well (Wolpin, 1997). On the other hand, this raises a general issue with the child survival production function, that it is in general impossible to measure all relevant inputs, especially lagged inputs. Given the econometric model adopted here, addressing all these issues is beyond the focus of the paper.
11. Identification via non-linearity might be far less satisfactory than relying on exclusion restrictions, and, thus the estimation results of demand equation should be interpreted with caution. Unfortunately, it is usually very difficult to have exclusion restrictions in this type model, because all the variables affecting one health input will also affect the other health inputs. However, using irrelevant identifying variables might also do harm rather than do good (John Bound, David A. Jaeger, and Regina M. Baker, 1995).

12. The NSS does not contain reliable information on income. See John Strauss and Duncan Thomas (1995) for pros and cons of using different measures of income. Also see Angus Deaton (1997) for the difficulties of measuring income as well as consumption in developing countries. Because I am predicting the per capita expenditure using a different data set, the estimated coefficient of per capital expenditure may not be efficient.
13. See Rakesh Munshi and Sang-Hyop Lee (2000) for issues of measuring immunization coverage in India.
14. The survival probability is $\hat{S}(t) = 1 - \hat{h}(t)$, where the hazard function is a form of $\ln \hat{h}(t) = x\hat{\beta}$. Because health care inputs are dummy variables, the difference in survival probability between any dummy variable and the base category is $(1 - e^{\beta_s}) - (1 - e^0)$, which equals $1 - e^{\beta_s}$.
15. The use of hybrid production function including per capita household expenditure barely changes the results (not shown in the table).

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