THE DEMAND FOR REPRODUCTIVE HEALTH SERVICES:
AN APPLICATION OF CONTROL FUNCTION APPROACH

by

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Abstract

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Problem statement. Sub-Saharan Africa has the worst indicators of reproductive health in the world. Reproductive health indicators such as maternal and infant mortality rates are highest in this region. Low birth weight is a summary indicator of reproductive health but its determinants are not obvious. We use the control function approach to investigate the determinants of low birth weight on the basis of which we propose policy interventions.

Research Methods. We employ a control function approach to estimate the effect of tetanus vaccination on birth weight using cross-section data from Kenya. A structural model of birth weight determination is estimated under the assumption that tetanus vaccination is complementary to health inputs and behaviours that improve birth weight, namely: prenatal care, food supplements, and behavioural change during pregnancy. The first-stage regression estimates the reduced form parameters of a demand function for tetanus vaccination in which instruments for vaccination include money- and time-prices of health services. The effect of sample selectivity on the estimated structural parameters in the second-stage regression is also investigated because birth weight is censored.

Results and conclusion
We find that birth weight is positively associated with tetanus vaccination. This association is *indirect* as it comes from the hypothesized complementarity between vaccination and birth weight. Consistent with the previous literature (Dow *et al*., 1999), the complementarity hypothesis cannot be rejected with the Kenyan data. However, disaggregation of data by mother's residence and income suggests that the complementarity effect on birth weight is driven by unobserved variables, such as mother's knowledge of essential health services and behaviours that enhance birth weight. Policies to promote such care and behaviours are discussed in a concluding section.

1. INTRODUCTION

Like other welfare indicators, reproductive health is the outcome of consumption of both reproductive health care and other goods and services. In many developing countries, the availability as well as the consumption of reproductive health services is limited by a combination of economic, social and technological factors. As a consequence, low-income countries, especially in Africa have poor indicators of reproductive health such as maternal mortality ratio, infant mortality and total fertility rates. There is need to find ways of expanding provision and consumption of reproductive services in sub-Saharan Africa to improve the general health of the population in the region, which currently remains low because essential reproductive health care is lacking. The key components of reproductive health care include family planning, safe delivery services, prenatal and postnatal care, treatment of placental malaria, nutrient supplements during pregnancy and behaviours that promote fetal growth. The consumption of these forms of health care enhances reproductive health. As in any demand situation, the utilization of reproductive health care inputs is constrained by market and non-market environments. The market environment includes availability of reproductive health inputs and their prices, and household income. The non-market environment comprises the household residence (a rural or an urban setting), personal characteristics of household members, such as age, education, health status, and the information they possess about the quality of reproductive health care services.

Demand analysis can help understand the types of policies that should be implemented to improve access to reproductive health care and thus improve child health. In much of the health care demand literature, the connection between health consumption and health production is only implied, but is not explicitly made (see e.g., Gertler and Van der Gaag, 1990). This paper explicitly links demand for reproductive health services with health production using birth weight as a measure of reproductive health. Like general health, reproductive health is the complete well-being of persons at particular life cycles, and not merely the absence of disease or infirmity (WHO, 1948).

2. DEMAND FOR REPRODUCTIVE HEALTH SERVICES

We analyze demand behaviour for reproductive health services by a mother using a model in which child is embedded in a utility function. The model was first proposed by Rosenzweig and Schultz (1982). The application presented here is draws heavily from Ajakaiye and Mwabu (2007) and Mwabu (2007). A mother's one-period utility function can be written as:

$$U = U\,(X, Y, H) \qquad (1)$$

where,

X = a health neutral good, i.e., commodity that yields utility, U, to a mother but has no direct effect on reproductive health status of the mother, e.g., clothing;
Y = a health-related good or behavior that yields utility to the mother and also affects birth weight, e.g., smoking and alcohol consumption;
H = Health status of the child, measured by birth weight.

Following the original notation of Rosenweig and Schultz (1982), the birth weight production function is expressed as

$$H = F\,(Y, Z, \mu) \qquad (2)$$

where,

Z = purchased market inputs such as medical care that affect child health directly;
μ = the component of child health due either to genetic or environmental conditions.

The mother maximizes (1) given (2) subject to the budget constraint given by equation (3)

$$I = XP_{\mathrm{x}} + YP_{\mathrm{y}} + ZP_{\mathrm{z}} \qquad (3)$$

where,

I is exogenous income;
P_x, P_y, P_z are, respectively, the prices of the health-neutral good, X (such as clothing), health-related consumer good, Y (such as quitting smoking) and health investment good, Z (e.g., tetanus immunization). Notice from equations (1) and (2) that the health investment good is purchased only for the purpose of improving child health so that it enters the mother's utility function only through H.

The birth weight production function in equation (2) has the property that it is imbedded in the constrained utility maximization behavior of the mother (equations 1 and 3). Expressions (1)-(3) can be manipulated to yield reproductive health care demand functions of the form

$$X = D_x (P_x, P_y, P_z, I, \mu) \qquad (4.1)$$

$$Y = D_y (P_x, P_y, P_z, I, \mu) \qquad (4.2)$$

$$Z = D_z (P_x, P_y, P_z, I, \mu) \qquad (4.3)$$

The effects of changes in prices of the three goods on child health can be derived from equations (4.1- 4.3) since from equation (2), a change in child health can be expressed as

$$\mathrm{d}H = F_y \mathrm{X} \mathrm{d}Y + F_z \mathrm{X} \mathrm{dZ} + F_\mu \mathrm{X} \mathrm{d}\mu \qquad (5)$$

where,

F_y, F_z, F_μ are marginal products of reproductive health inputs Y, Z and μ , respectively (see equation (2)).

From the equation (2), the change in health can be related to changes in respective prices of reproductive health inputs as follows

$$\mathrm{d}H/\mathrm{d}P_x = F_y \mathrm{X} \mathrm{d}Y/\mathrm{d}P_x + F_z \mathrm{X} \mathrm{d}Z/\mathrm{d}P_x + F_\mu \mathrm{X} \mathrm{d}\mu/\mathrm{d}P_x \qquad (6.1)$$

$$\mathrm{d}H/\mathrm{d}P_y = F_y \mathrm{X} \mathrm{d}Y/\mathrm{d}P_y + F_z \mathrm{X} \mathrm{d}Z/\mathrm{d}P_y + F_\mu \mathrm{X} \mathrm{d}\mu/\mathrm{d}P_y \qquad (6.2)$$

$$\mathrm{d}H/\mathrm{d}P_z = F_y \mathrm{X} \mathrm{d}Y/\mathrm{d}P_z + F_z \mathrm{X} \mathrm{d}Z/\mathrm{d}P_z + F_\mu \mathrm{X} \mathrm{d}\mu/\mathrm{d}P_z \qquad (6.3)$$

where,

$\mathrm{d}\mu/\mathrm{d}P_i = 0$, for i = x, y, z so that in equation (6), the terms $F_\mu \mathrm{X}(.) = 0$, since μ is a random variable unrelated to commodity prices.

3. DATA, ESTIMATION ISSUES AND RESULTS

3.1 Data and hypothesized relationships

This section is drawn from Ajakaiye and Mwabu (2007, pp. 21-36). The survey data used to jointly estimate the demand for tetanus immunization and the birth weight production function include immunization of mothers during pregnancy, user charges for health care services, household income and assets, birth weight, whether a child was delivered at home or at a health facility, education of parents, and the time mothers spent on household chores such as collection of water and firewood. These data were collected in 1994 by the Government of Kenya through the Central Bureau of Statistics, Ministry of Planning and National Development (see Mwabu, 2007b).

In this application, child health is measured by birth weight. Birth weight is a good indicator of health of the child in the womb because the weight is taken immediately after birth. Thus, a malnourished fetus will be born at low birth weight. The key determinants of birth weight include nutritional status and age of the mother, the quantity and quality of prenatal care services received by the mother, mother's immunization against preventable diseases and behavioral change during pregnancy such as quitting smoking. Other factors such as areas of residence, which are proxies for availability of health care and nutrients, also affect the health of the child in utero.

Immunization against tetanus during pregnancy is used as a proxy for antenatal care services received by a woman. Immunization against tetanus is further assumed to be complementary to other inputs that improve the health of the child in the womb, such as presumptive malaria treatments and avoidance of risky behaviors. A thorough analysis of the complementarity hypothesis (the competing risk model) is in Dow et al. (1999). Dow et al. observe that "…a woman will increase inputs into birthweight when she believes that the EPI will be available to increase the child's chances of surviving…" (p. 1362). Tetanus vaccination for pregnant women is one of the major components of EPI (Expanded Program on Immunization), a world-wide vaccination initiative sponsored by the World Health Organization, which also provides maternal services to women such as safe delivery and post-natal care.

In accordance with the complementarity argument, we assume that expectant women who received tetanus vaccination during the 1994 Kenyan survey were more likely to engage in demand behavior that increased birth weight than women who were not immunized. The key argument is not that tetanus vaccination directly increases birth weight, but that vaccination is strongly correlated with health care consumption and behaviors that increase birth weight.

The general complementarity idea is that when a specific cause of a health problem is removed, other background causes follow suit, because people have incentives to also remove them. For example, a reduction in the risk of child death via immunization against tetanus, automatically reduces the risk of child death due to low birth weight. Stated differently, the adoption of a specific behavior, or the uptake of a specific input that improves health, creates incentives to engage in other health-augmenting behaviors or consumption.

The above complementarities, which are analytically captured by Leontief preferences and technologies, are forms of positive social externalities of an intervention, i.e., large indirect and often unanticipated benefits of an innovation. For example, an intervention that improves obstetric care has a larger benefit than that associated with the reduction in the risk of infant deaths at birth. The obstetric care intervention could also give mothers an incentive to behave in ways that improve birth weight, thus reducing the risk of infants dying due to low birth weight.

However, mother's immunization against tetanus immunization could also induce moral hazard, a form of a negative social externality. For example, knowing that immunization against tetanus protects them and their newborns from a tetanus infection during child-birth, the mothers might choose to deliver at home rather than at clinics. Such a choice could expose the newborn to death risks associated with poor general care during delivery, despite being at good health in utero.

We estimate demand for tetanus vaccination simultaneously with a model of birth weight determination. In the birth weight model, vaccination is assumed to improve child health in line with the complementarity hypothesis. Indeed, a positive empirical relationship between birth weight and tetanus vaccination is consistent with complementarity hypothesis.

3.2 Measurement issues

Equation (2) is the appropriate framework for measuring the effect of tetanus vaccination on birth weight when *Z* is interpreted as tetanus vaccination, and *H* as birth weight. In equation (2), tetanus vaccination is endogenous to birth weight because it is a choice variable. Thus, instruments for tetanus vaccination are needed in order to consistently estimate the effect of vaccination on birth weight. The instruments for tetanus vaccination are factors that affect demand for tetanus vaccination without influencing directly the birth weight. These institutional and supply-side factors are household land holdings, household rent income, prices of health care, and the amount of time women spend to collect water.

When estimating equation (2), there is further need to deal with potential sample selection bias because some of the children in the 1994 survey did not have birth weight. In particular, children born at home rather at clinics did not have birth weights. The Heckman procedure (Heckit) is used to deal with the sample selection bias (Wooldridge, 2002). The first step in the application of the Heckit procedure is the identification of the probit equation. That is, specification of factors that influence selection of the unit of study into the estimation sample without directly affecting birth weight. In our case, the unit of analysis is a child. A child was included into the estimation sample only if he or she had a birth weight extracted from a growth-monitoring card. The factors that identify the sample selection equation are the same as those that identify the demand for tetanus vaccination. Moreover, the heterogeneity of birth weight due to non-linear interaction of tetanus vaccination with unobservables and omitted variables could bias the estimated structural coefficients. The control function approach (Garen, 1984; Wooldridge, 1997; and Card, 2001) is used to address this issue.

Following Wooldridge (2002; Mwabu, 2007b) the estimation strategy may be summarized as follows.

$$B = \boldsymbol{w}_1 \ast_{b} + \exists \boldsymbol{M} + ,_1 \qquad (7.1)$$
$$M = \mathbf{w} \ast_{m} + ,_2 \qquad (7.2)$$
$$G = \mathbf{1}(\mathbf{w} \ast_{g} + ,_3 > 0) \qquad (7.3)$$

where,

B,*M*, *G* are birth weight, immunization status of the mother, and an

indicator function for selection of the observation into the sample, respectively;
$\boldsymbol{w}_1$ = a vector of exogenous covariates;
$\mathbf{w}$ = exogenous variables, consisting of $\boldsymbol{w}_1$ covariates that belong in the birth weight equation and a vector of instrumental variables, $\boldsymbol{w}_2$, that affect immunization status, M, but have no direct influence on birth weight, B;
*, ∃, , = vectors of parameters to be estimated, and a disturbance term, respectively.

Notice from equations (7.2) and (7.3) that the instruments for $\boldsymbol{M}$ and $\boldsymbol{G}$ are the same. In the recent literature, the endogenous explanatory variables are commonly referred to as "treatment variables" (see Strauss and Thomas, 2007). This terminology stresses the fact that the most credible way to measure the effect of an endogenous variable on the outcome of interest (i.e., to identify *treatment effect*) is to vary the endogenous variable experimentally. In an experimental setting, this variation is achieved through a random assignment of units of study into *treatment* and *control* groups. The word "treatment" is used to indicate that a section of the study sample is "treated" (its characteristic of interest, such as immunization, is varied exogenously). Since this variation occurs when other causal factors are held constant, it is possible to identify the effect of the characteristic on outcome variable of interest, e.g., birth weight. In the absence of an experiment, such a variation is achieved through an econometric procedure, with the aid of a structural model (see Schultz and Strauss, 2007).

Equation (7.1) is the structural equation of interest, i.e., the birth weight production technology whose parameters are to be estimated. Equation (7.2) is the linear projection of the potentially endogenous variable, M, on all the exogenous variables, $\mathbf{w}$, i.e., a reduced form linear probability model of vaccination.

The third equation (7.3) is the probit for sample selection. It is the probability of a mother's child being included in the estimation sample. It captures the fact that in the household survey, the mothers who did not deliver at the clinics generally did not report birth weights for their children. Since the children without birth weights are excluded from equation (7.1), equation (7.3) helps correct any sample selection bias in the estimated parameters. The correction factor, derived from equation (7.3), is the inverse of the Mills ratio.

To accommodate any non-linear interactions of unobservable variables with the birth weight regressors, and to account for sample selection bias, equation (7.1) is rewritten as

$$B = \forall_0 + \boldsymbol{w}_1 \bullet * + \exists \bullet \boldsymbol{M} + \forall_1 \bullet \boldsymbol{V} + (\bullet (V \times \boldsymbol{M} + \lambda \bullet \boldsymbol{Mills} + u \qquad (7.4)$$

where

V = Fitted residual of *M* (observed value of *M* minus its fitted value), derived from a linear probability model;
V $\times$ ***M*** = Interaction of the fitted immunization residual with the actual value of the immunization status;
Mills = Inverse of the Mills ratio;
u = A composite error term comprising $,_1$ and a predicted part of $,_2$, under the assumption that $E(,_1) = 0$;
δ, β, α, γ, and λ = parameters to be estimated.

The exclusion restrictions are imposed in equation (7.4) because the vector of instruments, $\boldsymbol{w}_2$ (for immunization status, ***M***), is absent from the equation. The terms ***V***, (***V***$\times$***M***), and ***Mills*** in equation (7.4) are the control function variables because they control for the effects of unobservable factors that would otherwise contaminate the estimates of structural parameters.

The reduced form immunization residual, ***V***, serves as the control for unobservable variables that are correlated with ***M***. In particular, if an unobserved variable is linear in ***V***, it is only the intercept, $\forall_0$, that is affected by the unobservable, and thus the IV estimates of equation (7.4) are consistent even without the inclusion of the interaction term. The interaction term, (***V***$\times$***M***), controls for the effects of any neglected non-linear interaction of an unobservable variable with the immunization status of the mother. Specifically, if the effect of ***M*** on birth weight is influenced by an unobserved variable, say, *a* (which is correlated with ***M***), this unobserved influence (*a*$\times$***M***) is relegated to the structural error term and its source neglected during estimation. The estimated coefficient on ***M*** contains this neglected effect of unobserved variables; other structural coefficients may be similarly affected. Inclusion of the interaction term, (***V***$\times$***M***), in equation (7.4) purges the estimated coefficients of the effects of unobservables (see Card, 2001).

Empirically, an unobserved variable, say *a*, is represented by the reduced form immunization residual. The interaction (multiplication) of ***V*** with ***M*** captures the idea that the size of *a* varies non-linearly with ***M***. Thus, its unobserved and neglected effect (*a*$\times$***M***) changes in a non-linear way as ***M*** changes. The inverse of the Mills ratio holds constant the effects of the non-random sample on structural parameters. Although the polynomials of the fitted residual term, $\boldsymbol{V}$, and its interactions with exogenous covariates, i.e. **w**, can also be included in equation (7.4), the practice in the literature is to omit them or include them selectively (see Garen, 1984; Wooldrige, 2005). It is possible to test which of the various versions of equation (7.4) are consistent with data (see Mwabu, 2007b).

The IV estimates of equation (7.4) are unbiased and consistent only when one or the other of the following conditions holds (a) the expected value of the interaction between immunization and its fitted residual ($V \times M$) is zero; (b) the expectation of the interaction between immunization and its fitted residual is linear (see Wooldridge, 1997).

Equation (7.4) can be estimated using the MLE procedure in STATA or similar software. Thus, inclusion of the inverse of the Mills ratio in equation (7.4) as a regressor is redundant, because both its sample value and its coefficient are automatically generated upon convergence of the likelihood function.

3.3 Estimation Results, 1

Table 3.1 shows how tetanus immunization affects birth weight, controlling for other covariates of interest, notably the age and area of residence of the mother. As noted previously, immunization is a proxy for health care inputs that improve birth weight such as nutrition intake of the mother (Fogel, 2004). Table 1 summarizes estimation results obtained from equation (7.4) under different assumptions.

3.1: Estimation of vaccination demand and birth weight functions under different assumptions

Variables	Estimation Methods				
	OLS	*Heckit* (ML procedure)		*Control Function Approach* (DependentVariable = birthweight	
Sample Selection Variable (= 1 if birth weight is not missing)	Birth weight equation	Sample Selection Variable (1=if birth weight >0)	Birth weight equation	Linear Interaction of vaccination with unobservables	Non-linear interaction of vaccination with unobservables
Mother's Vaccination Status (1=vaccinated)	.1349 (3.96)		.1273 (3.71)	.2894 (2.19)	.5886 (2.55)
Age of mother, years	.0197 (4.12)	-.0121 (1.24)	.0199 (4.21)	0.0182 (3.69	.0182 (2.97)
Age of mother squared (x 10^{-3})	-.2746 (4.27)	.1374 (1.02)	-.2734 (4.30)	-.2426 (3.49)	-.2450 (2.72)
Sex of the Child (1 = Male)	.0986 (5.67)	.0001 (0.00)	.0981 (5.64)	.0984 (5.66)	.0979 (5.64)
Area of Residence (1 = Rural)	-.3803 (1.73)	-.3307 (5.96)	-.0306 (1.35)	-.0328 (1.46)	-.0328 (1.31)
Identification Variables (affect sample selection but not birth weight)					
Log of household Land Holding		-.1379 (6.97)			
Log of Household Rent Income		.0220 (4.92)			
Mother's education		.0855 (18.5)			
Father's education		.0197 (4.78)			
Minutes spent to fetch water in *wet* season per day, cluster median (x10^{-3})		-2.245 (3.17)			

Minutes spent to fetch water in *dry* season per day, cluster median (x10^{-3})		-2.616 (8.02)			
User charges (KSh) at private health facilities, cluster median (x10^{-3})		-.7475 (3.77)			
Control function Variables (account for birthweight effects of unobservables in the error term)					
Reduced form vaccination residual				-.1655 (1.22)	-.5508 (2.16)
Vaccination status x Vaccination residual					.6041 (2.45)
Inverse of the Mills Ratio [s.e]		-.0351 [.0302]			-.0159 [.0457]
Constant	2.705 29.10	.3059 (1.70)	2.719 (29.2)	2.575 (18.1)	2.700 (9.80)
R-squared	0.016				
Wald statistic [*p*-value]		69.35 [0.000]			
Ho: Correlation between reduced form immunization error term and the structural error term = 0 [*p*-value]					0.24 [0.623]
Sample sizes	4162	7838	4162	4162	4162
Total observations Censored obs	7838 3676				

3.4 Discussion of Results, 1

Table 3.1 shows the link between the demand for reproductive health care and health status at the earliest stage of the life cycle. The results of demand for tetanus immunization from the full sample (the first-stage regression) are not reported in Table 3.1. Table 3.2 reports these estimates by residence and household income. The results show that age and education of the mother, household land assets and income, and money and time costs of general health care, strongly affect utilization of vaccination services. The results are consistent with previous research in this area (see Ainsworth et al., 1996; Gertler and van der Gaag, 1990; Acton, 1975). It is should be noted that the instruments for the selection equation (Table 3.2, middle panel) are the same as the instruments for immunization equation (see Table 3.3 below).

The results in Table 3.1 show that birth-weight is strongly associated with tetanus immunization. The pattern of coefficients on mother's age in all specifications has an inverted U-shape, indicating that younger mothers are more likely than older women to deliver heavier babies. Moreover, in all specifications, males are heavier at birth than females.

It is evident from Table 3.1 that the size of the effect of tetanus vaccination on birth weight depends on estimation method. Thus, it is important to use proper estimation method to avoid misleading policy conclusions. The properly estimated effect of vaccination (the last column) is nearly 5 times greater than the OLS estimate (first column). The problems due to endogeneity and neglected non-linearities are revealed by a comparison of the Heckit estimates with the estimates derived via the control function approach. The Heckit estimate of the effect of immunization on birth weight is 0.1273 (which is close to the OLS estimate of 0.1349), indicating that the coefficient changes very little with the removal of the sample selection bias. However, when immunization status of the mother is endogenized, the coefficient more than doubles to 0.289. Moreover, accounting for non-linear interactions of immunization with unobservables further increases the coefficient to 0.588. This estimate shows that immunization (a proxy for the quality of health care received by the mother during pregnancy) substantially increases birth weight. In particular, tetanus immunization in Kenya increased birth weight by nearly half a kilogram in 1994.

The column labeled sample selection variable, presents information on determinants of demand for births at health facilities because in this data set, reporting of a birth weight by mothers is strongly associated with a clinic birth. The probit results associated with the structural parameter estimates shown in the last column of the table are not reported. An interesting finding from the probit estimates is that rural mothers are less likely to deliver at the clinics compared with urban mothers, and that land holding reduces the probability of a clinic birth. These two findings are related because rural settings are associated with large land holdings. Household income and education increase the probability of reporting a birth weight. However, money prices of general health services and the time spent on collecting water reduce this probability.

The coefficient on reduced-form immunization residual (last column) is statistically significant (*t*-ratio =2.16). However, the coefficient on the inverse of the Mills ratio is insignificant, suggesting that sample selection bias is not a problem in this data set. That is, birth weight is not associated with the demand for clinic birth. The special case of the control function approach (the linear interaction of vaccination with its fitted residual) is interesting because the estimated coefficients of the birth weight technology under this specification are identical to the usual IV estimates. The estimates (except for the standard errors) correspond to those obtained under the strict assumption that the covariance between vaccination (the endogenous variable) and its fitted residual is zero (see Wooldridge, 1997).

The coefficient on the fitted residual without controls for non-linear interactions is .1655 (*t*-ratio =1.22). However, with the controls for non-linear interactions between vaccination and unobservables, this coefficient increases to 0.5508 (*t*-ratio = 2.16), indicating that vaccination status is endogenous to birth weight. The control function approach is the appropriate estimation strategy because it takes into account both the endogeneity of vaccination, and the heterogeneity of response of birth weight to vaccination. The heterogeneity arises from non-linear interaction of vaccination with unobserved determinants of birth weight, such as the biological endowment of the mother and her environment. Inclusion of the control function variable, ($V \times M$), in the birth weight equation purges the estimates of any effects of heterogeneity. The descriptive statistics associated with Table 3.1 are in appendix tables A1 and A2.

3.5 Estimation Results By Residential Area and Household Income

Tables 3.2 and 3.3 present estimation results by residential area and household income. Household exogenous income is per capita *rent* income per month. The household income is *low* if it is Ksh 700 or below (which was the food poverty line in 1994 (see Republic of Kenya, 1996)), and is *high* if it is more than Ksh 1,500.

Table 3.2: A Linear Probability Model of Demand for Tetanus Vaccination: Dependent Variable Equals One if Mother was Vaccinated During Pregnancy and Equals Zero Otherwise (*t*-statistics in Parentheses)

Variables	Rural and urban sub-samples		Income sub-samples	
	Rural	Urban	Rural Low Income	Rural High Income
Age of mother, years	.0081 (2.63)	.0125 (1.49)	.0080 (2.29)	.0207 (1.95)
Age of mother squared (x 10^{-3})	-.1624 (3.81)	-.2208 (1.64)	-.1617 (3.39)	-.3762 (2.28)
Sex of the Child (1 = Male)	-.0034 (0.35)	-.0004 (0.02)	-.007 (0.56)	.0188 (0.91)
Area of Residence (1 = Rural)	--	--	--	--
Identification Variables (affect demand for immunizations but not birth weight)				
Log of household Land Holding	.0243 (3.64)	.0211 (1.45)	.0279 (3.43)	-.0049 (0.34)
Log of Household Rent Income	.0044 (3.16)	-.0005 (0.27)	.0093 (3.59)	-.0117 (0.75)
Mother's education	.0116 (7.52)	.0039 (1.59)	.0131 (7.21)	.0053 (1.44)
Father's education	.0014 (1.06)	.0046 (2.45)	.0025 (1.59)	-.0022 (0.71)
Minutes spent to fetch water in *wet* season per day, cluster median (x10^{-3})	-.9046 (3.28)	-2.293 (2.97)	-.9091 (2.92)	.1835 (0.22)
Minutes spent to fetch water in *dry* season per day, cluster median (x10^{-3})	-.812 (6.16)	.591 (1.40)	-.9577 (5.89)	-.5218 (2.12)

User charges (KSh) at private health facilities, cluster median ($x10^{-3}$)	.1546 (1.13)	-.2671 (5.23)	.4085 (2.41)	-.0464 (0.18)
Constant	.7364 (13.43)	.7348 (5.85)	.7150 (11.18)	.7438 (3.67)
R-squared	0.094	0.059	0.118	0.038
Sample sizes	3372	790	2448	602

Table 3.3: Estimation of birth weight production functions using the Control Function Approach; by residential area and household income: dependent variable is birth weight in kg (*t*-statistics in parentheses)

Variables	All	Rural	Urban	Rural Low Income	Rural High Incom
Mother's Vaccination Status (1=vaccinated)	.5886 (2.55)	.2982 (1.27)	2.069 (1.76)	.6422 (2.49)	-2.10 (2.57)
Age of mother, years	.0182 (2.97)	.02195 (3.40)	.0135 (0.64)	.0167 (2.36)	.066 (2.68)
Age of mother squared ($x\ 10^{-3}$)	-.2450 (2.72)	-.3052 (3.28)	-.1875 (.55)	-.2352 (2.33)	-.9571 (2.50)
Sex of the Child (1 = Male)	.0979 (5.64)	.0856 (4.41)	.1525 (3.92)	.0843 (3.73)	.0714 (1.53)
Area of Residence (1 = Rural)	-.0328 (1.31)	--	--	--	--
Control function Variables (account for birthweight effects of unobservables)					
Reduced form vaccination residual	-.5508 (2.16)	-.2178 (0.82)	-2.38 (1.84)	-.6049 (2.07)	2.46 (2.78)
Vaccination status x Vaccination residual	.6041 (2.45)	.5186 (2.01)	2.49 (1.90)	.6341 (2.24)	-2.11 (2.33)
Inverse of the Mills Ratio [se]	-.0159 [.0457]	-.0594 [.046]	-.0545 [.1060]	-.0077 [.0579]	-.1496 [.0885]
Constant	2.700 (9.80)	2.489 (10.1)	.8491 (0.69)	2.22 (8.15)	4.251 (5.10)
Wald Statistic	58.35 (0.000)	54.69 (.000)	20.15 (.000)	45.34 (.000)	18.58 (.000)
Sample sizes	4162	3372	790	2448	602

3.6 Discussion of Results from Various Sub-samples

Tables 3.2 and 3.3 depict estimation results for tetanus vaccination demand and for birth weight production functions by area of residence of the mother and household income. The exclusion restrictions in Table 3.2 identify the immunization equation because the hypothesis that the coefficients on these restrictions are jointly equal to zero can be rejected (test results are available from authors on request). The top panel in Table 3.2 shows that age of the mother affects demand for tetanus vaccination. This effect is evident in all sub-samples. In particular, demand for tetanus vaccination first increases with age of the mother and then falls, indicating that younger mothers are more likely to use tetanus immunization services compared with older women. This finding is mirrored in the upper panel of Table 3.3 where the effect of mother's age on birth weight first rises before it falls, indicating that the mean birth weight among younger mothers is higher than among older women.

In Table 3.2, land and income are shown to be important determinants of demand for tetanus vaccination in rural areas and among low-income mothers in rural areas. However, in urban areas and among high-income rural mothers, these variables have no effect on demand. Restricting attention to demand effects of land and income, it can be seen that rich mothers in rural areas have immunization demand patterns similar to demands for average mothers in urban areas. The correlations of demand with education are quite interesting. In rural areas, a mother's education is positively correlated with utilization of tetanus immunization services. However, in urban areas, a woman's own education is weakly correlated with demand for tetanus immunization. Instead, the main determinant of a woman's demand for vaccination is her spouse's education. Among high-income mothers in rural areas, education is not associated with demand for immunization. In contrast, women's education is strongly correlated with demand for tetanus immunization among poor rural households.

The opportunity cost of time is negatively associated with demand for tetanus vaccination in virtually all specifications. However, the signs of coefficients on the money prices charged for immunization services differ between rural and urban sub-samples. In the rural sub-sample, the coefficient on the money price is positive, which contradicts the law of demand; it is possible that in rural areas service prices are positively associated with service quality.

Table 3.3 shows the control function parameter estimates of the birth weight production function. The table shows estimates of the structural parameters of the birth weight equation using different sub-samples. Except in the case of the high-income rural sub-sample, the effect of tetanus vaccination on birth weight is positive, a finding that is consistent with the complemantarity hypothesis (Dow et al., 1999). The last column of Table 3.3 suggests that mothers from high-income rural households have consumption or behavioral preferences that negatively affect birth weight. For example, although vaccinated mothers from high-income households have an incentive to invest in better nutrition, in accordance with the complementarity hypothesis, they also have greater opportunities to engage in consumption and behaviors that reduce birth weight, such as smoking and drinking. Grossman (1972) reported a similar finding in the context of general health. Apart from the negative coefficient on immunization, the magnitude of this coefficient is implausibly large. Another notable finding from Table 3.3 is that male newborns are heavier than females in all sub-samples, which is an indication that this estimate is quite robust.

The coefficients on reduced form immunization residual and on the interaction term, both indicate that the unobservables indeed have an effect on birth weight. See Table 3.3, column 1, which is a repetition of Table 3.2, last column. However, these effects are not stable across sub-samples (see the control function estimates in Table 3.3). As can be seen from Table 3.3, the coefficient on immunization is 0.2982 in the rural sample, but is nearly seven times as large (2.069) in the urban sample. Moreover, the variability of this coefficient is even greater between the high-income rural sub-sample (0.6422) and the low-income sample (-2.10) in the same area. There are many possible sources of this variation. One potential source is the type of information or counseling that mothers receive while at sites of immunization services. High-income rural mothers are more likely to both smoke and/or drink and to use immunization services. That is, immunization in a high-income area is likely to be negatively correlated with birth weight, because of the negative effects of smoking and drinking on birth weight. As already noted, although mothers from such a sample are likely to be better nourished, the positive effect of nutrition on birth weight could easily be outweighed by the negative effects of factors associated with high income. The coefficient on the inverse of the Mills ratio is statistically insignificant in all sub-samples, suggesting that sample selection bias is not a problem in this Kenyan data set. However, this finding should be interpreted with caution (see Glick, 2007).

4. CONCLUSION

The paper has reviewed a variety of demand frameworks, and illustrated how the frameworks can be used to inform policies for improving reproductive health of the population. The frameworks have the following key features. First, they can help identify constraints to utilization of commodities and services that are essential for improving reproductive health. Second, they provide an economic approach to the analysis of individual and household behaviors that promote reproductive health, thereby facilitating an interdisciplinary research on such behaviors, e.g., effects of smoking and breastfeeding on maternal and child health. Third, the very specification of these frameworks is likely to motivate policy makers to take demand estimates to the next stage of examining the effects of service utilization on health. Fourth, intra-household variations in reproductive health and in demands for reproductive health services and commodities can be studied using the frameworks. However, because of data limitations, it was not possible to provide an illustrative application of an intra-household model in this essay. Nonetheless, the theoretical frameworks provide insights of how to formulate policies for addressing inequalities in reproductive health within the household.

Some of the frameworks can be estimated using existing data sets. The Kenyan example presented in this paper demonstrates this feasibility. The control function estimates of the birth weight production function suggest that the information that mothers possess about health-improving technologies plays a critical role in motivating them to invest in behaviors and consumption that complement tetanus immunization in increasing birth weight. A mother's immunization against tetanus while pregnant reduces the risk of a child dying from tetanus infection during delivery. As a consequence, the complementary hypothesis of the competing risk model (Dow et al., 1999) predicts that mothers would be strongly motivated to reduce other risks to child survival, e.g., the risk of a child dying from syndromes associated with a low-birth weight.

The mechanisms through which pregnant mothers reduce this risk include investing in better nutrition, avoiding smoking and drinking, and using prenatal care services. These are elements of a health production technology. Unless mothers possess information about this technology, they are unlikely to adopt behaviors and consumption patterns that are complementary to tetanus immunization in improving child health. For example, mothers could receive vaccination against tetanus, and continue to smoke or consume alcohol because they lack information about harmful effects of these types of consumption on the fetus. Such information can be provided at immunization clinics. The information would reduce or close any knowledge gaps existing among women who receive tetanus immunization at clinics.

We hypothesize that the heterogeneity of information on health-improving practices and technologies among women is the source of variation in birth weight across income levels observed in Table 3.3. There is need therefore to investigate the content of health education extended to mothers in different regions and at different clinics during vaccination days. Standardization of such information would enable women to have access to the same reproductive health care technology. As a consequence, immunization of mothers against tetanus (or implementation of safe delivery interventions) would be accompanied by behavior and consumption patterns that increase rather than reduce child health.

More generally, the results in Table 3.3 suggest the need for health facilities and health policy makers to do more than simply immunize mothers. They suggest the need for *immunization plus* interventions. Specifically, when receiving immunizations, mothers should be counseled about other things they can do to maintain their health and that of their unborn children. Data on the content of the counseling that occurs during immunization days would help design immunization plus programs. Such data would be particularly germane to the immunization plus campaigns if it captures existing counseling practices in both rural and urban areas.

If the information contents of counseling are exactly the same in rural and urban areas, then there would be a basis for nuanced counseling over space and across income levels, and across other characteristics of mothers such as occupation, education and age. The information on the content of existing immunization programs would also provide a basis for pointing out the imperatives for effective empowerment of women (not giving out doles to them but providing sound education and training especially to young women and promoting remunerative employment for mothers). Indeed, the *immunization plus* interventions provide the link between reproductive health, economic growth and poverty reduction. The unified demand framework presented in the paper helps the policy makers evaluate how participation in *immunization plus* interventions empowers women by improving their health, equipping them with useful skills, and connecting them to productive livelihoods. The collective household model that informs demand analysis can be used to assess whether empowerment of women benefits the whole family.

Because of data limitations, it was possible to illustrate empirically only a few of the frameworks presented in this paper. For example, to implement intra-household models, information is needed on exogenous income or resources that are controlled by various household members. Panel data are also required to analyze why some household members engage in practices that promote reproductive health while other members do not. A case in point is why some mothers deliver at clinics while others consistently choose to deliver at home. In addition to quantitative data of the type analyzed in this paper, qualitative data might be necessary to answer these sorts of questions. Experimental data may also be needed to deal with difficult issues of inference and policy, e.g., why is fertility high in some regions or households? What is the effect on women's health of a fertility decline? Additional data sets are also needed to analyze the relationship between reproductive health and poverty dynamics.

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Appendix Tables

Appendix Table A1: Descriptive statistics, uncensored sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Birth weight	4162	3.175709	.5653995	1	5
Immunization	4162	.9137434	.2807763	0	1
Predicted imm	4162	.9137434	.082934	-.1094432	1.114153
Pred residual	4162	-1.32e-10	.2682486	-1.038387	.8044392
Mother age	4162	29.2852	6.991334	16	91
Immun x resid	4162	.07194	.0710595	-.1141534	.8044392
Mother age sq	4162	906.4899	490.9636	256	8281
Sex (male=1)	4162	.5057665	.5000268	0	1
Rural (=1)	4162	.8101874	.3921999	0	1
Log land	4162	.9089697	.7845221	0	4.61512
Log rent income	4162	2.906136	3.586057	0	11.05091
Mother education	4162	6.909178	3.82128	0	16
Father education	4162	6.891567	4.480119	0	16
Water min, wet	4162	17.51562	21.01926	0	360
Water min., dry	4162	26.65017	42.44428	0	780
User fees, private	4162	35.14031	78.5439	0	1265.83

Appendix Table A2: Descriptive statistics, full sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Birth weight, kg	4174	3.175419	.5649474	1	5
Immunization (=1)	7861	.8252131	.3798089	0	1
Predicted immuniz	7838	.8679894	.1435308	-.1275014	1.114153
Immuniz residual	7838	-.0430341	.3395746	-1.044042	.9328943
Age mother,years	7861	30.24539	7.645715	15	91
Immuniz x resid	7838	.0840497	.0898886	-.1141534	.9328943
Age mother square	7861	973.233	554.098	225	8281
Sex child (1=Male	7861	.502735	.5000243	0	1
Rural (=1)	7861	.8707544	.335493	0	1
Birthweight report	7861	.5309757	.4990713	0	1
Log land	7838	.9974064	.8516709	0	5.303305
Log rent income	7861	2.581198	3.441401	0	11.05091
Mother education	7861	5.441547	4.221362	0	16
Father education	7861	5.685116	4.631377	0	16
Water minutes, Wet	7859	26.45731	43.74528	0	480
Water minutes, dry	7859	49.19112	100.1076	0	780
User fees, private	7861	32.11538	82.32426	0	2389.583