Annex 19A Health Gains and Financial Risk Protection Afforded by Treatment and Prevention of Diarrhea and Pneumonia in Ethiopia: An Extended Cost-Effectiveness Analysis

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1. Introduction

This supplementary appendix describes the methods used for the extended cost-effectiveness analysis (ECEA) of universal public finance (UPF) for diarrhea treatment, rotavirus vaccination, pneumonia treatment, pneumococcal conjugate vaccination interventions, in Ethiopia. Specifically, we estimate the level and distribution (across income groups) of:

(1) the burden of disease averted (under-five deaths averted);
(2) the out-of-pocket (OOP) private medical expenditures averted;
(3) the total incremental costs to the government;
(4) the financial risk protection (FRP) afforded, measured by a money-metric value of 'insurance' provided.

We divide the population in five income groups *J*, and we define: *y*, the income of an individual, and *f(y)*, the income distribution.

2. Treatment interventions

For each treatment intervention (diarrhea, pneumonia), the intervention targets Ethiopian under-five children i.e. $Pop_{<5}$.

Let $p_{inp,J}$ and $p_{out,J}$ denote the probabilities of inpatient and outpatient visit for the treatment among income group J conditional on having the disease and seeking care; $c_{inp,OOP}$ and $c_{out,OOP}$ the OOP costs for inpatient and outpatient visit for disease treatment among income group J; $c_{inp,gov}$ and $c_{out,gov}$ the government costs for inpatient and outpatient visit for disease treatment. The intervention has an effectiveness Eff, the incremental coverage achieved by the program is Cov, and the coverage before the program is $Cov_{ante,J}$, which varies between income groups J.

2.1. Deaths averted

We estimate the number of deaths averted by the program in income group J by:

$$D_{post,J} = Eff * Cov * D_{ante,J} \,, \quad (1)$$

where $D_{ante,J}$ is the annual number of under-five deaths related in income group J in Ethiopia before the program as estimated with the Lives Saved Tool (LiST) [1,2] and as given in the main text (figure 1).

2.2. Consequences for household expenditures

We estimate the household expenditures averted in the following manner in each income quintile J by:

$$PE_J = Cov_{ante,J} * (p_{inp,J} * c_{inp,OOP} + p_{out,J} * c_{out,OOP}) * Inc_{J,<5} \,, \qquad (2)$$

where $Inc_{J,<5}$ is the total annual number of incident cases among under-five children related to income group J.

2.3. Program costs

From the government perspective, the incremental costs incurred are:

$$TC = [Cov_{ante,J} * (p_{inp,J} * c_{inp,OOP} + p_{out,J} * c_{out,OOP}) + Cov * (p_{inp,J} * (c_{inp,gov} + c_{inp,OOP}) + p_{out,J} * (c_{out,gov} + c_{out,OOP}))\,]\, Inc_{J,<5} \,, \qquad (3)$$

2.4. Financial risk protection afforded – money-metric value of insurance

We apply a standard utility-based model where risk-averse individuals are exposed to uncertainty, intend to reduce that uncertainty, and consequently value the protection from the risk of uncertain adverse events [3-5]. Individuals have the choice between two scenarios: a scenario with an uncertain gamble; a scenario with a certain outcome. Risk-averse individuals prefer the certain scenario with possibly lower income rather than the scenario with uncertain income. In what follows, we estimate the individual's income in both the uncertain and certain scenarios. The subsequent difference in income then quantifies the income the individual is willing to lose to obtain certainty about the outcome.

In the uncertain scenario, we estimate the expected value of the gamble associated with the eventuality (uncertainty) of diarrhea/pneumonia treatment with probability p and cost c, before UPF is introduced. Our focus in this chapter is on the cost of treatment and excludes transportation costs and the cost of earnings or productivity reduced by the disease. That said, the model could be expanded to include these additional costs. In the uncertain scenario, the expected value of income (green point E(Y) on figure S.1) to an individual of income Y in the quintile J of the gamble with rotavirus treatment prior to the vaccination program is:

$$E_J(y) = p_{inp,J} * (y - c_{inp,OOP}) + p_{out,J} * (y - c_{out,OOP}) + (1 - p_{inp,J} - p_{out,J})y \qquad (4)$$

For the certain scenario, we utilize a constant relative risk aversion utility function: $U(y) = \frac{y^{1-r}}{1-r}$, for $r > 0$ and $r \neq 1$ and where y is the income and r is the Arrow-Pratt coefficient of relative risk aversion. Here we choose $r = 3$ (figure S.1) [3-5]. In the certain scenario, we estimate the income the same individual is willing to have in order to have a certain outcome. This income is called the 'certainty equivalent' (red point CE on figure S.1), denoted Y_J*, which we derive from the expected value of the utility (expected utility) of the individual with the uncertain income $E[U(Y)]$:

$$E[U(y)] = p_{inp,J} * U(y - c_{inpOOP}) + p_{out,J} * U(y - c_{out,OOP}) + (1 - p_{inp,J} - p_{out,J}) * U(Y) \quad (5)$$

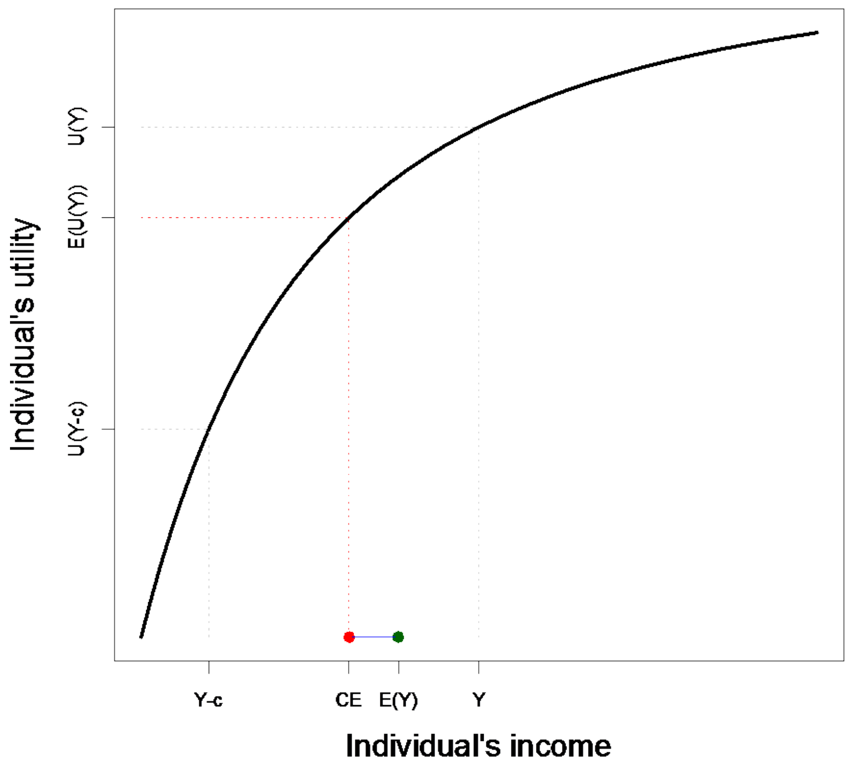
and:

$$\begin{aligned} Y_J^* = U^{-1}[E(U(y)] &= U^{-1}[p_{inp,J} * U(y - c_{inp,OOP}) + p_{out,J} * U(y - c_{out,OOP}) \\ &+ (1 - p_{inp,J} - p_{out,J}) * U(y)] \\ &= [p_{inp,J} * (y - c_{inp,OOP})^{1-r} + p_{out,J} * (y - c_{out,OOP})^{1-r} + \\ &(1 - p_{inp,J} - p_{out,J}) Y^{1-r}]^{\frac{1}{1-r}} \end{aligned} \quad (6)$$

Consequently, for the individual in quintile *J*, the difference between the expected value of income and the 'certainty equivalent' quantifies the income the individual is willing to lose to obtain a certain outcome, hence it yields the money-metric value of 'insurance' (risk premium) provided by the vaccine program, or FRP value, for the individual in quintile *J*:

$$\begin{aligned} V_J &= E_J(y) - Y_J^* \\ &= p_{inp,J} * (y - c_{inp,OOP}) + p_{out,J} * (y - c_{out,OOP}) \\ &+ (1 - p_{inp,J} - p_{out,J}) * y - [p_{inp,J} * (y - c_{inp,OOP})^{1-r} + p_{out,J} * (y - c_{out,OOP})^{1-r} + (1 - p_{inp,J} - p_{out,J}) * Y^{1-r}]^{\frac{1}{1-r}} \end{aligned} \quad (7)$$

Figure S.1 Individual's utility (constant relative risk aversion utility) as a function of individual's income.



Equation (7) summarizes how the value of insurance (*V*) varies with the magnitude of risk (*p*), income *y*, cost of diarrhea/pneumonia treatment (*c*) and risk aversion (*r*). Subsequently, FRP for the quintile *J* (per capita) is estimated as:

$$FRP_J = \int_J (E_J(y) - Y_J^*) f(y) dy \qquad (8)$$

where *f* is a Gamma density based on country gross domestic product (GDP) per capita and Gini index [6,7].

3. Vaccine interventions

We divide the population in five income groups *J*, and we define: *y*, the income of an individual, and *f(y)*, the income distribution; $p_{inp,J}$ and $p_{out,J}$ the respective 5-year probabilities of inpatient and outpatient visit for rotavirus diarrhea/pneumococcal pneumonia among income quintile *J*; $c_{inp,OOP}$ and $c_{out,OOP}$ the respective OOP costs for inpatient and outpatient visit for rotavirus diarrhea/pneumococcal pneumonia; $c_{vaccine}$ the price of rotavirus/pneumococcal vaccine (per dose) and $c_{program}$ the vaccination program cost (per dose). The vaccine has an effectiveness V_{eff} and the coverage achieved by the program is *Cov*.

3.1. Under-five deaths averted

We estimate the number of rotavirus/pneumococcal deaths averted over five years by the program in a given country, using rotavirus- and pneumococcal-related mortality as estimated by the Lives Saved Tool (LiST) [1,2] (see figure 1 in the main text). By income quintile *J*, the rotavirus/pneumococcal deaths averted are:

$$D_{Post,J} = V_{eff} * Cov * D_{ante,J} \quad (9)$$

where $D_{ante,J,}$ is the number of under-five rotavirus/pneumococcal deaths in income quintile *J* in Ethiopia before the program, V_{eff} is the vaccine effectiveness, and *Cov* is the vaccine coverage.

3.2. Consequences for household expenditures

We estimate the household medical expenditures averted (rotavirus diarrhea/pneumococcal pneumonia costs averted by the program). For the income quintile *J* (per capita):

$$PE_J = V_{eff} * Cov * (p_{inp,J}\, c_{inp,OOP} + p_{out,J}\, c_{out,OOP}) \quad (10)$$

3.3. Costs to the government to sustain the vaccination program

From the government perspective, the vaccination costs incurred (per capita) are:

$$TC_{RV} = n\, Cov\, (c_{vaccine} + c_{program}) \quad (11)$$

where $c_{vaccine}$ and $c_{program}$ are the costs (per dose) of the vaccine and the program, respectively; $n = 2$ for rotavirus vaccine and $n = 3$ for pneumococcal conjugate vaccine.

3.4. Financial risk protection afforded – money-metric value of insurance

We apply a standard utility-based model where risk-averse individuals are exposed to uncertainty, intend to reduce that uncertainty, and consequently value the protection from the risk of uncertain adverse events [3-5]. Individuals have the choice between two scenarios: a scenario with an uncertain gamble; a scenario with a certain outcome. Risk-averse individuals prefer the certain scenario with possibly lower income rather than the scenario with uncertain income. In what follows, we estimate the individual's income in both the uncertain and certain scenarios. The subsequent difference in income then quantifies the income the individual is willing to lose to obtain certainty about the outcome.

In the uncertain scenario, we estimate the expected value of the gamble associated with the eventuality (uncertainty) of rotavirus/pneumococcal disease treatment with probability *p* and cost *c*, before the vaccination program is introduced. In the uncertain scenario, the expected value of income (green point E(Y) on figure S.1) to an individual of income *y* in the quintile *J* of the gamble with rotavirus treatment prior to the vaccination program is:

$$E_J(y) = p_{inp,J}(y - c_{inp,OOP}) + p_{out,J}(y - c_{out,OOP}) + (1 - p_{inp,J} - p_{out,J})y \quad (12)$$

For the certain scenario, we utilize a constant relative risk aversion utility function: $U(y) = \frac{y^{1-r}}{1-r}$, for $r > 0$ and $r \neq 1$ and where y is the income and r is the Arrow-Pratt coefficient of relative risk aversion ($r = 3$ [3-5], figure S.1). In the certain scenario, we estimate the income the same individual is willing to have in order to have a certain outcome. This income is called the 'certainty equivalent' (red point CE on figure S.1), denoted Y_J*, which we derive from the expected value of the utility (expected utility) of the individual with the uncertain income $E[U(y)]$:

$$E[U(y)] = p_{inp,J}U\left(y - c_{inp,OOP}\right) + p_{out,J}U\left(y - c_{out,OOP}\right) + \left(1 - p_{inp,J} - p_{out,J}\right)U(y) \quad (13)$$

and:

$$Y_J^* = U^{-1}[E(U(y))] = U^{-1}[p_{inp,J}U\left(y - c_{inp,OOP}\right) + p_{out,J}U\left(y - c_{out,OOP}\right) + \left(1 - p_{inp,J} - p_{out,J}\right)U(y)] = [p_{inp,J}(Y - c_{inp,OOP})^{1-r} + p_{out,J}\left(Y - c_{out,OOP}\right)^{1-r}\left(1 - p_{inp,J} - p_{out,J}\right)Y^{1-r}]^{\frac{1}{1-r}} \quad (14)$$

Consequently, for the individual in quintile *J*, the difference between the expected value of income and the 'certainty equivalent' quantifies the income the individual is willing to lose to obtain a certain outcome, hence it yields the money-metric value of 'insurance' (risk premium) provided by the vaccine program, or FRP value, for the individual in quintile *J*:

$$V_J = E_J(y) - Y_J^* = p_{inp,J}\left(y - c_{in,OOP}\right) + p_{out,J}\left(Y - c_{out,OOP}\right) + \left(1 - p_{in,J} - p_{out,J}\right)Y - [p_{inp,J}(Y - c_{inp,OOP})^{1-r} + p_{out,J}(Y - c_{out,OOP})^{1-r} + \left(1 - p_{inp,J} - p_{out,J}\right)Y^{1-r}]^{\frac{1}{1-r}}$$
(15)

Equation (15) summarizes how the value of insurance (*V*) varies with the magnitude of risk (*p*), income *y*, cost of rotavirus/pneumococcal disease treatment (*c*) and risk aversion (*r*). As only a fraction of the population (*Cov*) receives the vaccine of efficacy V_{eff}, the money-metric value of FRP for the quintile *J* (per capita) is:

$$FRP_J = V_{eff}Cov \int_J \left(E_J(y) - Y_J^*\right)f(y)dy \quad (16)$$

where *f* is a Gamma density based on country GDP per capita and Gini index [6,7].

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