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Public finance of rotavirus vaccination in India and Ethiopia: An extended cost-effectiveness analysis

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ABSTRACT

Background: An estimated 4% of global child deaths (approximately 300,000 deaths) were attributed to rotavirus in 2010. About a third of these deaths occurred in India and Ethiopia. Public finance of rotavirus vaccination in these two countries could substantially decrease child mortality and also reduce rotavirus-related hospitalizations, prevent health-related impoverishment and bring significant cost savings to households.

Methods: We use a methodology of 'extended cost-effectiveness analysis' (ECEA) to evaluate a hypothetical publicly financed program for rotavirus vaccination in India and Ethiopia. We measure program impact along four dimensions: 1) rotavirus deaths averted; 2) household expenditures averted; 3) financial risk protection afforded; 4) distributional consequences across the wealth strata of the country populations.

Results: In India and Ethiopia, the program would lead to a substantial decrease in rotavirus deaths, mainly among the poorer; it would reduce household expenditures across all income groups and it would effectively provide financial risk protection, mostly concentrated among the poorest. Potential indirect benefits of vaccination (herd immunity) would increase program benefits among all income groups, whereas potentially decreased vaccine efficacy among poorer households would reduce the equity benefits of the program.

Conclusions: Our approach incorporates financial risk protection and distributional consequences into the systematic economic evaluation of vaccine policy, illustrated here with the case study of public finance for rotavirus vaccination. This enables selection of vaccine packages based on the quantitative inclusion of information on equity and on how much financial risk protection is being bought per dollar expenditure on vaccine policy, in addition to how much health is being bought.

1. Introduction

About a third of global diarrhea-related deaths are attributed to rotavirus. In children younger than five years an estimated 4% deaths were the result of rotavirus-related diarrhea in 2010 [1,2]. The large majority of these deaths among under-fives were in low-income populations of Africa and Asia [1,2]. Five countries (the Democratic Republic of the Congo, Ethiopia, India, Nigeria and Pakistan) accounted for more than half of all rotavirus deaths [1–3].

The introduction of rotavirus vaccine into the vaccination schedule of lower income countries might lead to substantial reductions in child mortality and significantly reduce the number of rotavirus-related hospitalizations, as it has been observed in the (high-income) countries where implemented [4]. In sub-Saharan Africa and India, 90% of rotavirus-related hospitalizations occur among children under two years of age [5,6]. Though the efficacy of rotavirus vaccine, a standard two-dose regimen given at 6 and 12 weeks of age [7], has proven lower in the developing

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countries that are highly impacted by rotavirus [7,8],[1] even a partially effective vaccine there could save many lives and bring substantial cost savings to households possibly preventing them from medical impoverishment.

Rotavirus vaccination may be a very cost-effective intervention [9–14] which could save up to 2.5 million lives over the next 20 years in Global Alliance for Vaccines and Immunization (GAVI)-eligible countries [10]. Country-specific benefits from rotavirus vaccination will depend on the specific burden of diarrhea, vaccine price and efficacy, and the targeting of the vaccination programs [9,12,13]. Greater benefit should be expected in low-income countries, primarily because of high mortality levels. Within countries, greater benefit should be expected among the poorest populations who often have higher risks of death, reduced access to effective care, and bear significant economic costs due to disease treatment.

Health interventions such as rotavirus vaccination, and by extension the policy levers that finance and deliver them, have distributional consequences across wealth strata of populations which they target. Early work has shown that universal measles vaccination coverage could substantially reduce income-related mortality differentials in high mortality settings [15]. More recently, Rheingans et al. [16] examined the cost-effectiveness of rotavirus vaccination per income group in selected GAVI-eligible countries, and found it most cost-effective to vaccinate in low-income populations.[2]

Policy choices that affect vaccination coverage include public finance (PF) for routine administration of a specific vaccine, mass campaigns,[3] and conditional cash transfers to encourage utilization [17]. PF policy of vaccine programs has some specific and positive consequences. First, PF increases uptake and leads to widespread health gains. Second, PF can reduce household expenditures on health care and prevent medical impoverishment. Finally, PF can have differential impact across a population by level of income [18].

In this paper, we apply a methodology of extended cost-effectiveness analysis (ECEA) [18] to evaluate the consequences of vaccine policy in each of the dimensions described above. We illustrate our approach with the case study of PF for rotavirus vaccination in two countries with substantial rotavirus burden, India and Ethiopia. Both countries have substantial rotavirus burden, yet differ significantly epidemiologically and economically. In order to make decisions on the introduction of new vaccines, Indian and Ethiopian policymakers need estimates of vaccination costs and outcomes, which differ across socio-economic groups. Distributional aspects have implications for decisions about where to invest first. The ECEA approach adds distributional consequences and financial risk protection (FRP) considerations to the decision criteria. It enables selection of vaccines based on quantitative inclusion of how much FRP is provided, as well as how much health is gained, per dollar expenditure on a policy [18].

2. Methods

We evaluate PF for rotavirus vaccination at survey-reported levels of DPT2 (2nd dose of Diphteria-Pertussis-Tetanus vaccine)[4] coverage in India and Ethiopia, drawing from standard cost-effectiveness methods [21]. In each country, we follow a hypothetical cohort of 1,000,000 births over the first five years of life. Rotavirus-related mortality outcomes and household expenditures are estimated for this cohort. The five-year horizon captures all relevant effects with simplicity: one cohort is modeled, and under-five children constitute the population group in which outcomes mostly occur and for whom data (e.g. burden of disease) is available. We adopt a societal perspective and consider the vaccination costs borne by providers (e.g. governments), separated from the rotavirus-related expenditures borne by patients and their families.

We estimate the level and distribution (across income groups) of the rotavirus deaths averted; the households' expenditures (direct medical costs and transport costs) related to rotavirus treatment averted ('private expenditures crowded out') and the costs needed to sustain the program (vaccination costs borne by the government); and the financial risk protection afforded by the program measured by an imputed money-metric value of 'insurance' provided, which we describe in detail in the supplementary data (Section 1.3).

2.1. Data sources

Values for all parameters are listed (Table 1). Before program introduction, individuals pay out of pocket for rotavirus treatment and the demand (utilization) and cost of this service vary by income group [20,23–32]. Vaccine effectiveness is assumed to be 43% and 49% for India and Ethiopia, respectively (consistent with trial data from Bangladesh and Malawi [33,34]); vaccine price is $2.50 per dose as currently procured to the GAVI Alliance [35]. We assume the program would achieve a similar coverage across all income groups equal to mean DPT2 coverage reported from survey data [19,20],[4] the incremental cost of vaccine administration to be $0.25 per dose based on the World Health Organization Global Immunization Vision and Strategy costing model [10,36].

2.2. Rotavirus deaths averted

The model follows a birth cohort of 1,000,000 individuals over five years and uses an indicator of relative rotavirus mortality ('risk index') varying by income group in order to quantify the reduction in under-five mortality due to rotavirus, in each income group, an approach which was implemented elsewhere [16]. Before the vaccination program, the rotavirus burden of disease is distributed across income groups, based on the risk index specified by income group (Table 1). The approach is static; in the case of rotavirus, vaccination may provide some protection to unvaccinated individuals due to herd immunity, which has been documented in a few (high-income) countries [37–39]. In section 3.2.3, herd effects are imputed into our model in order to estimate possible additional benefits of indirect protection due to vaccination.

[1] Many hypotheses have been suggested to explain this difference in efficacy of live oral rotavirus vaccines between developing and developed countries, including breastfeeding practices, micronutrient malnutrition, or differences in rotavirus epidemiology [7]. This difference is most likely linked to the levels of antibody transferred from the mother to the infant which can inhibit the infant immune response to the vaccine.

[2] Given the same vaccination cost per income group.

[3] Mass campaigns are commonly implemented for vaccines such as measles or polio but may not be appropriate for rotavirus vaccine which has to be given within a very specific time schedule.

[4] Survey-reported DPT2 coverage [19,20] was used to estimate the fraction of newborns that would receive the two doses of rotavirus vaccine. DPT2 coverage is meant to capture a realistic country health system capacity and to represent achievable vaccine coverage. DPT2 coverage was 76% in India in 2008 [19] and 52% in Ethiopia in 2011 [20].

Table 1
Parameters used for the base case scenario for the economic evaluation of public finance for rotavirus vaccination in India and Ethiopia.

Parameter	India estimate	Ethiopia estimate	Reference(s)
Rotavirus deaths (per 1000 live births)	3.7	5.4	Based on [1,2,22]
Relative risk ratio of rotavirus mortality (poorest to richest) {risk index, poorest to richest}	2.8 {1.43, 1.22, 1.02, 0.82, 0.50}	2.9 {1.34, 1.23, 1.06, 0.91, 0.46}	Based on [16]
Mean 5-year probability of inpatient visit for rotavirus diarrhea {poorest to richest}	3% {2, 4, 3, 2, 2}	2% {2, 2, 2, 3, 3}	Based on [20,23–27]
Mean 5-year probability of outpatient visit for rotavirus diarrhea {poorest to richest}	38% {37, 37, 37, 42, 39}	26% {18, 19, 27, 27, 38}	Based on [19,20,23,28–30]
Vaccine effectiveness (%) (per 2-dose course)	43	49	[33,34]
Vaccination coverage (%) (per 2-dose course)	76	52	Survey DPT2 coverage [19,20]
Mean out-of-pocket inpatient cost for rotavirus diarrhea (2011 US$)[a] {poorest to richest}	$82 {63, 64, 73, 96, 115}	$29 {25, 25, 25, 33, 38}	Based on [10,23,31,32]
Mean out-of-pocket outpatient cost for rotavirus diarrhea (2011 US$)[a] {poorest to richest}	$9 {8, 8, 7, 9, 14}	$9 {8, 8, 9, 11, 10}	Based on [10,23,31,32]
Vaccine price (per 2-dose course)	$5.0	$5.0	[35]
Vaccine price with GAVI subsidy (per 2-dose course)	[b]	$0.4	[35]
Incremental vaccination system cost (per 2-dose course)	$0.5	$0.5	[10,36]
Gross domestic product (GDP) per capita (2011 current US$)	$1489	$374	[32]
Gini index	33	30	[32]
Percent of households borrowing for rotavirus inpatient visit (mean amount borrowed)	31.7%[c] ($24)	N/A	[23]
Percent of households selling assets for rotavirus inpatient visit (mean amount obtained)	3.8%[c] ($2)	N/A	[23]
Percent of households borrowing for outpatient visit for rotavirus (mean amount borrowed)	7.9%[c] ($2)	N/A	[23]
Percent of households selling assets for outpatient visit for rotavirus (mean amount obtained)	0.3%[c] ($0)	N/A	[23]
Utility function as a function of individual income y	$y^{1-r}/(1-r)$; $r=3$	$y^{1-r}/(1-r)$; $r=3$	Based on [18] (Supplementary data)

DPT2, 2nd dose of Diphteria-Pertussis-Tetanus vaccine.

[a] Includes both direct medical costs and transport costs disbursed out of pocket.

[b] India's projected GDP per capita for 2013 is above $1520, hence, if India benefits from GAVI co-financing, the GAVI-subsidized price would start at 20% of the vaccine projected price (20% of $5.00 = $1.00) and increase gradually (by $1.00 increments) over four years to reach the projected price.

[c] The distribution of borrowing or selling assets among income groups is extracted from [46], and the ratio between poorest and richest households borrowing or selling assets is assumed to be 2.5. Ethiopians are assumed to borrow the same amount of money as Indians.

2.3. Consequences for household expenditures and government costs

From the patient perspective, we estimate (by income group) the amount of household expenditures averted for rotavirus treatment following program introduction. They represent cost savings from the household perspective. In each country, for the hypothetical cohort followed over five years, rotavirus-related expenditures borne by families, with and without vaccination, are estimated and depend on five-year probabilities of outpatient/inpatient visits for rotavirus and household expenditures for rotavirus-related outpatient/inpatient visits. Direct medical costs from outpatient/inpatient visits, and transport costs are included. Waiting time and travel time are not included. Informal medical treatment costs, and earning and productivity losses are excluded.

From the provider perspective, we estimate the total costs of the vaccination program to the government, depending on vaccine price and incremental administrative costs, and vaccination coverage.

2.4. Financial risk protection afforded

We quantify the FRP benefits brought to households by the program in monetary terms. For this purpose, we develop a money-metric value of FRP, in applying a standard utility-based model where risk-averse individuals value protection from the risk of uncertain events [18,40,41]. First, before the vaccination program is introduced, in the uncertain scenario, we estimate the expected value of the individual's income associated with the eventuality (uncertainty) of expenditures related to rotavirus with given probability and cost. Second, we use a utility function that depends on the individual's income and relative risk aversion (constant relative risk aversion utility function [42,43]). Using this utility-based framework, in the certain scenario, we estimate the income the individual is willing to have in order to have the outcome certain (named 'certainty equivalent'). Finally, the difference between the expected value of the individual's income and the income the individual is willing to have in order to have the outcome certain (i.e. the 'risk premium') yields a money-metric value of FRP provided by the program (by income group).

Complete details are given in the supplementary data (section 1). All analyses were conducted using Mathematica [44].

3. Results

We present our results for the base case scenario using standard data and four additional scenarios that consider i) changes in the vaccine price (3.2.1); ii) consequences of borrowing and asset selling (3.2.2); iii) addition of indirect benefits of vaccination (3.2.3); and iv) variations in vaccine efficacy according to income group (3.2.4). These extensions capture four important economic and epidemiological considerations that can, under different aspects, significantly impact the base case findings. We thus implement a scenario analysis to explore variations.

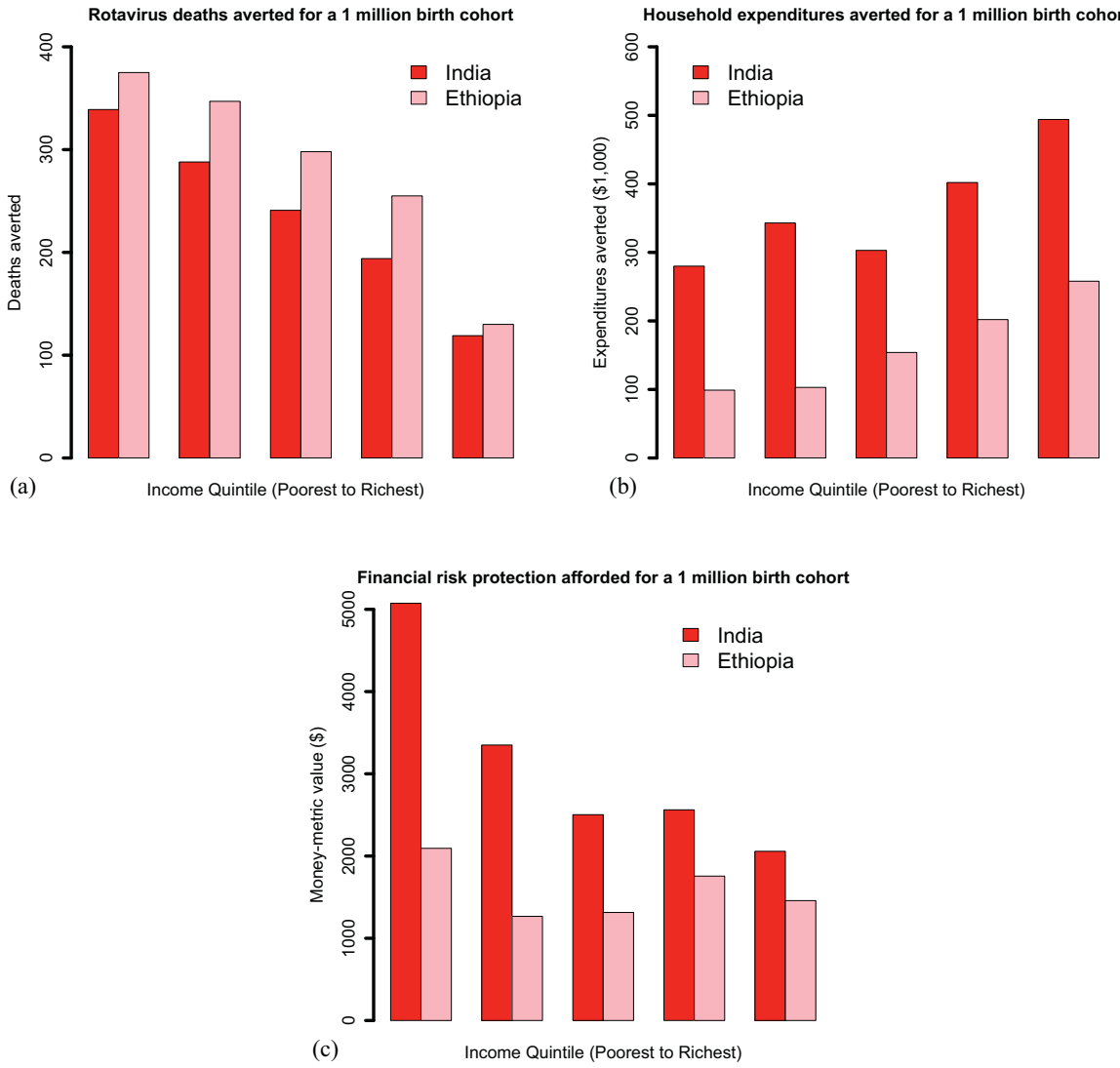

Fig. 1. Level and distribution of benefits for a 1,000,000 birth cohort followed over 5 years, with public finance for rotavirus vaccination at DPT2 current coverage, India and Ethiopia: Rotavirus deaths averted (a), household expenditures averted (b), financial risk protection afforded (c).

3.1. Base case scenario

For the base case scenario (Fig. 1), 32,000 lives would be saved in India (1200 per million births) representing 32% of all rotavirus deaths and 3700 lives in Ethiopia (1400 per million births) representing 26% of all rotavirus deaths. In India and Ethiopia, more lives would be saved among the bottom income quintile compared to the top income quintile (29% and 27% of benefits accrue to the bottom income quintile in India and Ethiopia). In India and Ethiopia, total household expenditures averted per million infants vaccinated would be $1,800,000 and $800,000, and the bottom two income quintiles would account for about 34% and 25% of all household expenditures averted. Total vaccination costs (assuming a cost of $5.50 per child vaccinated) incurred by the government would amount to $4,200,000 and $2,900,000. Total FRP (for 1,000,000 households) would be about $16,000 and $8000. The largest FRP value would be felt by the bottom income quintile in India (33% of total FRP) and Ethiopia (27%). A steeper gradient for rotavirus treatment utilization between the poorer and richer in Ethiopia, combined with a substantially lower average income ($374 vs. $1489 per capita), explains the trend of the FRP value as a function of income in Ethiopia.

3.2. Extensions to the base case scenario

3.2.1. Changes in the vaccine price

The GAVI Alliance offers a co-financing mechanism for low-income countries on a sliding scale according to their income level [35]. Specifically, countries with a gross domestic product (GDP) per capita lower than $1005 per annum can obtain a GAVI-subsidized vaccine price of $0.20 per dose: this is the case of Ethiopia. Countries with a GDP per capita above $1520 which have just 'graduated' from GAVI may pay 20% of the vaccine price the first year with a gradual increase over the following four years [35].

We explore how changes in vaccine price (which can reflect expected transitions when governments face market prices) may affect the results in terms of health gains and FRP afforded by the program. The number of deaths averted and FRP afforded per $1 million spent was examined among income groups for a few vaccine prices (Fig. 2). In each country, as vaccine price decreases, deaths averted and FRP afforded increase for any income group. In India, for a vaccine price of $2.00, a stated target price for vaccines currently being developed in India [45], $1,000,000 spent by the program would buy about $8000 of FRP and avert 630 deaths of which 33% of FRP and 29% of deaths averted would accrue among

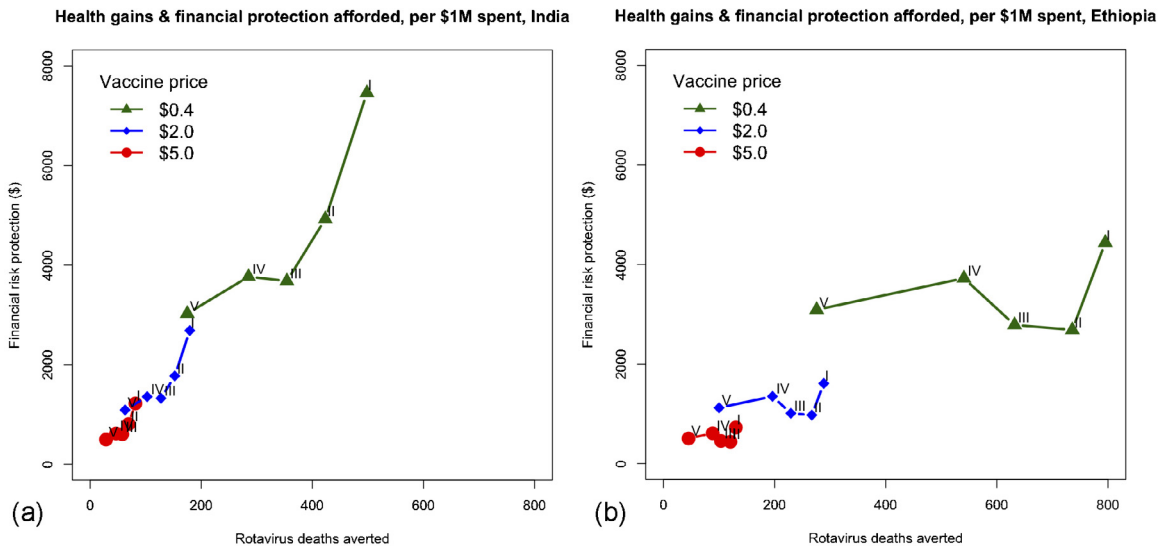

Fig. 2. Deaths averted and financial risk protection afforded over 5 years with the introduction of public finance for rotavirus vaccination at DPT2 current coverage, per $1,000,000 spent, as a function of vaccine price, India and Ethiopia. Income quintiles: I = poorest, II = poorer, III = middle, IV = richer, V = richest.

the bottom income quintile. In Ethiopia, for a vaccine price of $0.40, $1,000,000 would buy about $17,000 of FRP saving 3600 lives of which 27% of FRP and 27% of lives saved would accrue among the bottom income quintile. With vaccine prices of $2.00 and $0.40 in India and Ethiopia, for any income group, the deaths averted are larger in Ethiopia; however, the FRP afforded in India's bottom income quintile is similar to Ethiopia's second and third income quintiles.

3.2.2. Borrowing and asset selling

When faced with costly medical treatment, the poor use coping mechanisms such as borrowing from relatives and peers or selling assets [46]. We assume that borrowing or asset selling would concern individuals in all income groups, and that it would occur over a 10-year period where people would take a loan with a given interest rate (details are provided in the supplementary data, Section 2).[5] When a loan is started, the borrower's debt increases. Borrowing increases the expenditures the households would pay in the absence of the program. Hence, with the inclusion of borrowing in the analysis, the household expenditures averted and the FRP afforded increase. In particular, the FRP afforded increases as the borrowing interest rate increases (Fig. 3). Using a 40% annual interest rate, as reported in parts of India [47], we find substantially larger FRP values: $26,000 for India, 38% among the bottom income quintile; $17,000 for Ethiopia, 35% among the bottom income quintile. At a vaccine price of $2.00, the FRP afforded would represent 0.9% of total program costs ($1,900,000) in India. At a vaccine price of $0.40, the FRP afforded would represent 3.6% of total program costs ($500,000) in Ethiopia.

3.2.3. Indirect benefits of vaccination

Rotavirus vaccination may provide protection to unvaccinated individuals due to herd immunity, although evidence on herd effects from vaccination comes mostly from higher income countries where vaccine efficacy is high [37–39]. If herd effects in high-income country settings were replicated in developing country settings, where efficacy and coverage are lower, a vaccine with indirect protection could provide greater benefits than expected solely based on direct efficacy. In order to estimate the program benefits including this potential indirect protection, additional benefits of 1/3 are imputed to our results, based on published reports [37–39]. Expectedly, indirect vaccination effects may increase all benefits of the program by 1/3. For India, about 1600 deaths, 29% of which are among the bottom income quintile, would be averted; about $2,400,000 household expenditures, 34% among the bottom two income quintiles, would be averted; $21,000 FRP, 33% among the bottom income quintile, would be afforded, about 1.1% of total program costs. For Ethiopia, 1900 deaths, 27% among the bottom income quintile, would be averted; about $1,100,000 household expenditures, 25% among the bottom two income quintiles, would be averted; about $11,000 FRP, 27% among the bottom income quintile, would be afforded, about 2.2% of total program costs.

3.2.4. Vaccine efficacy varies by income group

We assume vaccine efficacy varies by income group: efficacy increases as individual income increases. This is consistent with trial data where lower/higher efficacy was demonstrated in lower/higher income countries [33,34,48–50]. In sub-Saharan Africa, the Rotarix trial [34] was conducted in two countries and three sites (two in South Africa and one in Malawi). In South Africa, the two sites were Soweto (middle class) and rural Pretoria (very poor): unpublished results demonstrated lower efficacy in rural Pretoria (personal communication), and Malawi had lowest efficacy. Live oral vaccine efficacy may differ in high-income vs. low-income populations due to immunological factors such as different titers of breast-milk antibodies [7,8]. Specifically, we observe a linear-log relationship between efficacy (V_{eff}) and GDP per capita [8] (Fig. 4):

$$V_{eff} \sim b_0 + b_1 \ln(GDP) \quad (1)$$

We find high goodness of fit ($R^2 = 0.81$), which validates the use of model (1) for our analysis. The coefficient on ln(*GDP*) implies that a 10% change in GDP per capita is associated with a 1.2% increase in vaccine efficacy. Using regression results from (1), we derive the following vaccine efficacies (from poorest to richest): {34, 38, 41, 46, 52}% for India and {41, 45, 48, 52, 58}% for Ethiopia.

Based upon these assumptions, the program benefits change (Fig. 5). Lives saved would decrease to 1100 for India and 1300 for Ethiopia, and be less concentrated among the bottom income quintile: 24% (270 deaths) for India; 23% (310 deaths) for Ethiopia. The

[5] 10 year is chosen for illustration purposes; the borrowing period may be much shorter as rotavirus diarrhea represents an acute event.

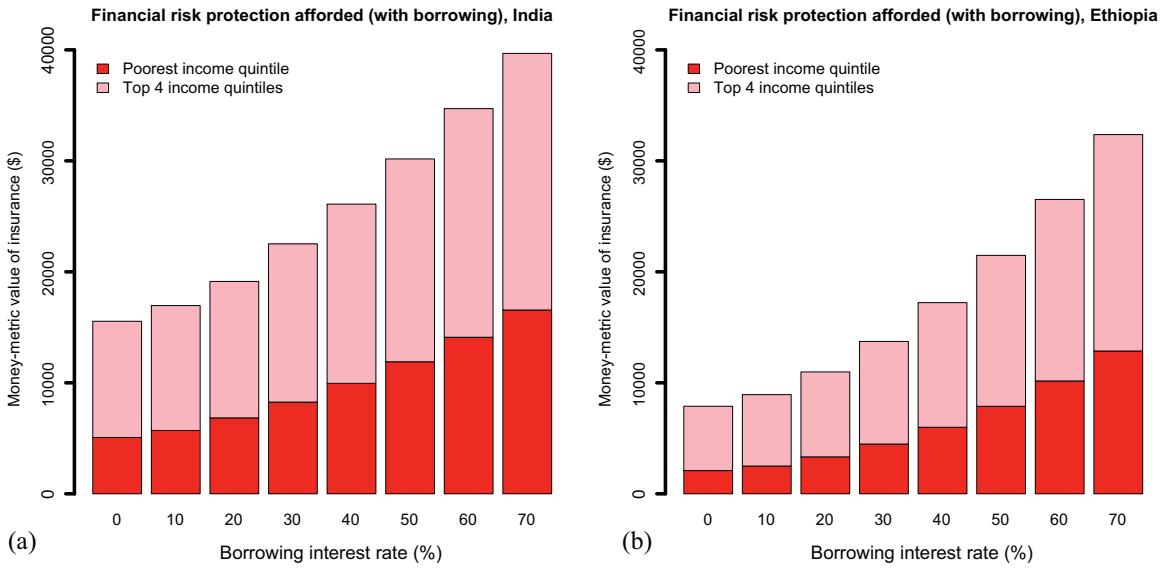

Fig. 3. Financial risk protection afforded (with borrowing included) for a 1,000,000 birth cohort followed over 5 years, with public finance for rotavirus vaccination at current DPT2 coverage, as a function of individual borrowing interest rate, India and Ethiopia.

household expenditures averted would remain of about $1,900,000 and $800,000, for India and Ethiopia. However, the bottom two quintiles household expenditures averted would now decrease to about 28% ($500,000) and 21% ($150,000). Total FRP afforded would decrease to $15,000 and $8000. The largest FRP would still be among the bottom income quintile in India (27%), but the gradient among income groups be diminished in India and Ethiopia.

4. Discussion

We evaluated the level and distribution of health and FRP benefits of PF for a rotavirus vaccination program in India and Ethiopia. We demonstrated that such program would lead to substantial reductions in rotavirus deaths, principally concentrated among the poorer and would avert household expenditures

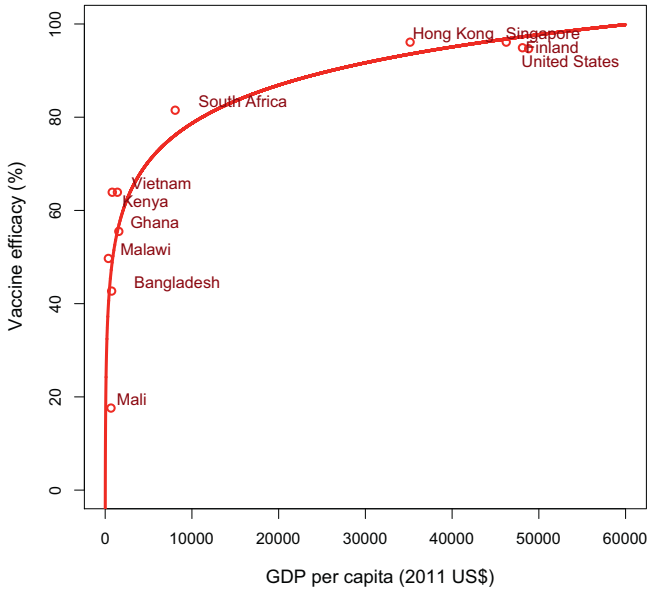

Fig. 4. Country point estimates of rotavirus vaccine efficacy as a function of country gross domestic product (GDP) per capita. Adapted from Nelson and Glass (2010) [8]. $V_{eff} \sim b_0 + b_1 \ln(GDP)$, where $b_0 = -30.2$ (Standard Error = 16.5, P = 0.10), $b_1 = 11.8$ (S.E. = 1.9, P < 0.001).

across all income groups. The program would provide FRP, mostly concentrated among the poorest. Comparatively, it would lead to a higher rate of rotavirus deaths averted in Ethiopia, as estimated mortality is higher there, and to higher FRP in India as Indians' healthcare utilization and household expenditures for rotavirus treatment are larger (Fig. 1).

Our results point to the importance of vaccine pricing, specifically GAVI co-financing. Ethiopia would face a GAVI-subsidized price ($0.20 per vaccine dose), and see larger health and FRP gains, per $ spent. India, being ineligible for GAVI support, would likely face a price of $1.00 per dose, see substantial, but smaller health and FRP gains per $ spent (Fig. 2). A steep rise in vaccine price, say after GAVI support expires, would dramatically alter the benefits: this is critical for low-income countries. Furthermore, we show that potential indirect benefits from vaccination may save additional lives and increase FRP, which points to data needs on herd effects of rotavirus vaccination in lower income settings. Herd immunity may indirectly 'reach out' to marginalized populations overlooked by health systems. It may therefore enhance equity, especially when decreased vaccine efficacy diminishes program benefits among the poorest (Fig. 5).

The analysis presents several limitations. First, settings are heterogeneous in income but also geographically (e.g. rural vs. urban) and epidemiologically. Heterogeneities entail economic differentials in costs (e.g. program costs) and quality (e.g. vaccine cold chain may be harder to maintain in certain areas), as well as epidemiological differentials in rotavirus mortality by age, for example. Notably, quality can differ substantially among sub-populations, and PF provision may enhance quality by crowding out bad treatment options (e.g. ineffective antibiotics). Dynamic modeling capturing herd effects and seasonality [51,52] could address some of these heterogeneities in spite of a critical lack of data, and also remedy the likely underestimation of health and FRP benefits without inclusion of herd immunity. In lieu of a dynamic model, using a 'back of the envelope' approach, herd effects were imputed into our model in order to estimate possible additional benefits of indirect protection due to vaccination. Herd effects may also differ by income quintiles as disease transmission differs among socio-economic groups. Likewise, when available, data on vaccine efficacy by population sub-groups in Ethiopia and India would be better than estimates based on country differences. Second, 'universal coverage' was not addressed. Universal coverage may be considered if

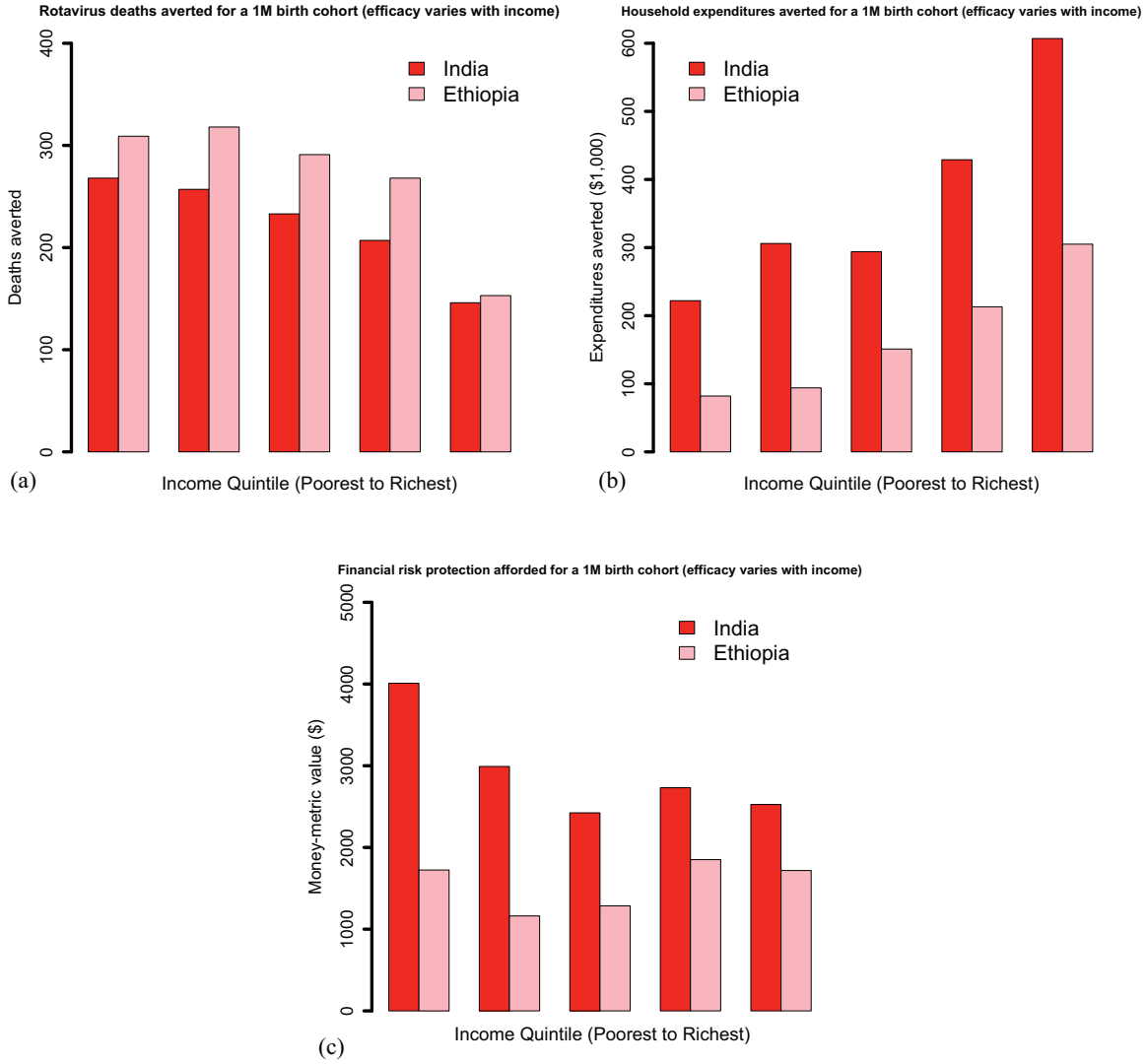

Fig. 5. Level and distribution of benefits for a 1,000,000 birth cohort followed over 5 years, with public finance for rotavirus vaccination at DPT2 current coverage, with varying vaccine efficacy among income groups, India and Ethiopia: Rotavirus deaths averted (a), household expenditures averted (b), financial risk protection afforded (c).

decision makers switch policy in order to extend coverage beyond levels currently achieved by health systems. For example, one could replace the use of routine vaccination by the use of mass campaigns or conditional cash transfers, at a certain point. Universal coverage may therefore be possible if the appropriate combination of policy levers and delivery platforms is implemented. Future work could consider long-term horizons targeting multiple birth cohorts. This would help policymakers understand how program benefits evolve, as vaccine price gradually changes over time. In addition, examining vaccine price and delivery by private entities and comparing with public provision would be valuable. Finally, future FRP measures would include productivity and earning losses associated with accompanying sick children to care, and PF of rotavirus vaccination would also be compared with scaling up of diarrhea treatment (e.g. oral rehydration therapy).

5. Conclusions

Using an ECEA approach [18], this paper presented a methodology for incorporating FRP and distributional consequences into the systematic economic evaluation of vaccine policy, illustrated here with the case study of public finance for rotavirus vaccination. In line with recently published works on the wider economic benefits of vaccination [53–56], our ECEA approach goes beyond traditional cost-effectiveness analysis in assessing consequences in three additional dimensions: protection against financial risks, direct household financial implications and distributional consequences across population strata. This enables selection of vaccine packages based on quantitative inclusion of information of how much FRP is being bought, as well as how much health is being bought with, say a million dollar expenditure on a vaccine policy (Fig. 2). The framework introduced can be applied to the comparative economic evaluation of a wide range of vaccines (e.g. pneumococcal, human papillomavirus) and policy levers such as conditional cash transfers or mass campaigns, in order to select, potentially, the vaccines to be included in vaccination schedules.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2013.07.014.

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