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The cost saving opportunity of introducing a card review into measles-containing vaccination campaigns

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ABSTRACT

Measles vaccination is a cost-effective way to prevent infection and reduce mortality and morbidity. However, in countries with fragile routine immunization infrastructure, coverage rates are still low and supplementary immunization campaigns (SIAs) are used to reach previously unvaccinated children. During campaigns, vaccine is generally administered to every child, regardless of their vaccination status and as a result, there is the possibility that a child that is already immune to measles (i.e. who has had 2 + vaccinations) would receive an unnecessary dose, resulting in excess cost. Selective vaccination has been proposed as one solution to this; children who were able to provide documentation of previous vaccination would not be vaccinated repeatedly. While this would result in reduced vaccine and supply cost, it would also require additional staff time and increased social mobilization investment, potentially outweighing the benefits. We utilize Monte Carlo simulation to assess under what conditions a selective vaccination policy would indeed result in net savings. We demonstrate that cost savings are possible in contexts with a high joint probability of an individual child having both 2+ previous measles doses and also an available record. We also find that the magnitude of net cost savings is highly dependent on whether a country is using measles-only or measles-rubella vaccine and on the required skill set of the individual who would review the previous vaccination records.

1. Introduction

Vaccines are an effective and affordable way to improve child health and reduce morbidity and mortality. Childhood immunization against infectious disease is performed globally, though routine coverage for the leading causes of vaccine-preventable illness is not yet universal. Even though a safe and cost-effective vaccine is available, global measles vaccination rates remained just below 85% in 2017 [1].

Despite a highly effective vaccine and aggressive programmatic targets for measles control and elimination [2,3], measles remains a major source of childhood morbidity and mortality worldwide [4]. In countries with fragile routine immunization infrastructures, national and sub-national measles pulse immunization campaigns are organized with the goal of reaching previously unvaccinated children. This approach is generally implemented in countries with routine vaccination coverage that is less than the 95% coverage target for two doses of measles-containing vaccine (MCV).

Historically, vaccination campaigns have served a variety of purposes within vaccination and control programs: to deliver a second dose of MCV to children in countries with only a single dose of MCV in their routine immunization schedule; to reach underserved children who have not received any doses of measles vaccine, which can happen for many reasons [5]; to rapidly interrupt chains of transmission and close accumulated immunity gaps [6]; and to respond to local measles outbreaks when necessary [7,8].

During campaigns, vaccine is generally administered to every child in the target age range, regardless of previous vaccination status. As a result, there is the possibility that a child who is already vaccinated with two or more doses of MCV would receive an additional dose. As seroconversion to two doses of measles vaccine is >95% [9], administration of the third+ dose could be considered unnecessary, since it imparts little or no immunity.

Selective vaccination campaigns are one potential way of reducing the amount spent on vaccines and supplies, and other work has explored potential epidemiological implications of targeted vs. non-selective vaccination in outbreak response [10] and maintenance campaign settings. In this work, we explore the cost implications of selective vaccination in follow-up campaigns (typically national campaigns targeting all children in a specified age range

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[11]): introducing a card review step and estimating the cost impact of using less MCV and fewer syringes, as well as the incremental cost of labor to perform the card review and the indirect impacts on transportation and social mobilization.

We demonstrate that cost savings are possible in some contexts with strong routine immunization and good vaccination card availability rates. We also show that the magnitude of the potential savings depends on programmatic considerations: the training level required of the person who reviews vaccination cards, the ability of the country to repurpose unopened vials, the targeted age range, and the amount of social mobilization required.

2. Methods

The proposed strategy under review in this paper is the introduction of a card review step into a supplementary immunization activity (SIA) vaccination campaign. This would be an additional step that is not currently performed and would require the caregiver (or the child) to bring documentation of their vaccination history to the campaign site. Upon arrival, a team member would review whether or not the child had previously received (and had documented) at least 2 doses of MCV; if so they would be offered an alternative intervention, if not the child would be vaccinated with MCV.

We took a programmatic perspective and considered only the direct impact of the policy on the cost of an SIA. We used historical Gavi-approved MCV campaign budgets as our primary data source for cost estimation, which are all given in US dollars [12]. This data was used in a Monte Carlo simulation model to estimate how much cost savings may be possible if a card review step and selective vaccination strategy was implemented.

The model consisted of three components: a calculation of doses purchased and the associated cost, an operational simulation of the vaccine doses used and wasted during a campaign, and a simulation of the cost parameters and calculation of the total budget impact.

We did not consider any health outcome impacts, since a third (or more) dose of MCV is not believed to be necessary for a child to achieve immunity [9]. Therefore, any dose that would not be delivered due to the card review is assumed to not impact disease burden.

For the purposes of this paper, we differentiate between home-based record (HBR) card retention and vaccination record availability. Card retention rates can be driven by a number of causes: HBRs may not have been printed (i.e. were out of stock in a clinic), may not have been distributed to the caregiver at time of vaccination, or may have been misplaced by the caregiver. To avoid implicating any particular cause, we use the term "vaccination record availability" for the remainder of this paper.

First, we estimate the reduction in MCV and injection supplies that would need to be purchased. Typically, enough MCV and supplies (including syringes and waste boxes) are purchased to vaccinate the entire targeted population, plus the expected wastage due to vials being opened but only partially used prior to expiration at the end of a campaign day. We utilized the WHO's standard wastage multiplication factor formula [11].

Thus, the calculation for the number of vials purchased for the baseline scenario was:

$$Baseline = (Population/Doses\ \ per\ \ Vial) * (100\%/(100\% - wastage\ \ rate))$$

The number of vials purchased under the card review scenario was the baseline value adjusted for reduced vaccine use due to MCV2 and card presentation rates. In addition, we included an incremental 5% buffer to cover the likely heterogeneities in card presentation that would otherwise have the potential to result in stock-outs of vaccine. The number of doses purchased in this scenario was constrained to be no more than the number purchased at baseline.

Additionally, we set a minimum purchase level as a percentage of baseline, in order to ensure that even in situations with very high MCV2 and card presentation rates, there is still some vaccine purchased and available for use during the campaign. This minimum purchase level was set based on systematic experimentation starting at 0% of baseline and increasing in 5% increments until there were no longer any simulation runs in which there would have been a shortage of vaccine (i.e. there was more vaccine used and wasted than vaccine that would have been purchased). After experimentation, we determined that the minimum purchase level required that never resulted in a vaccine shortage was 15% of baseline.

Thus, the number of vials to be purchased was:

$$Expected\ \ Use = Baseline * (100\% - MCV2\ \ Rate * Card\ \ Presentation\ \ Rate) * (100\% + buffer\ \ rate)$$

$$Vials\ \ Purchased = maximum(minimum(Expected\ \ Use,\ Baseline), Baseline * minimum\ \ purchase\ \ rate)$$

We calculated the supplies (syringes and waste boxes) to be purchased under each scenario, per the WHO's best practice guidelines [11]. The number of administration syringes is equal to the number of doses purchased; the number of reconstitution syringes is equal to the number of vials purchased; and the number of waste boxes is the number of total syringes purchased divided by a capacity of 100 per box. The other common immunization supplies include soap, trays, indelible marker pens, and AEFI treatment kits. These were excluded since they are based on the number of teams, which would not change under the proposed strategy, as every location will still need to be visited during the SIA, regardless of the anticipated number of vaccinations to be delivered.

Second, we used a Monte Carlo simulation model to generate a distribution of actual MCV and supply usage for both the baseline and card review scenario. The simulation was run in R (version 3.5.0), making use of packages ggplot2, plyr, dplyr, and truncnorm [13]. The simulation was run for a hypothetical target population of one million children, with parameters covering a range of possible scenarios, including MCV2 coverage rates ranging from 1 to 100 percent and card presentation rates ranging from 1 to 100 percent.

Each vaccination team is composed of two vaccinators plus two volunteers at a fixed post [11]. The simulation sampled the daily per-team target population from a uniform distribution between 200 and 300 [11]. Each simulated individual was assigned a vaccination status (vaccinated with 2+ doses or not) and card presentation status (presented card or not) using a binomial distribution for both parameters. We then calculated the number of vaccinations given, doses not given due to the individual's previous vaccination status, and vaccine wastage due to partially used vials at the end of each team-day for each simulation run.

We assumed that every child has an equal likelihood of having been previously vaccinated, of retaining their card, and of presenting their card. In reality, the population would not be perfectly mixed and these variables are likely correlated to some degree; we chose these assumptions since it is the most conservative approach to estimating potential savings.

Third, we applied a cost model to the outcomes of the Monte Carlo simulation (previous step) so that we could estimate the total cost impact of introducing a card review step into MCV vaccination campaigns. The cost model included MCV and supply savings, the

Table 1
Cost model structure. The cost model includes six budget categories: MCV and supplies, healthcare workers, volunteer incentives, training, transportation, and social mobilization. The Monte Carlo simulation calculates the savings potential for MCV and vaccination supplies and then simulates the increased costs associated with the remaining line items.

Programmatic Impact	Budget Line	Direction	Costs Included	Cost Model
Reduced use of MCV	MCV and Supplies	Savings	MCV vials Syringes Waste boxes Freight charges	A percentage savings was applied across the entire budget line, based on the anticipated reduction in the number of MCV planning doses
Addition of a card reviewer	HCW Resources	Cost	Campaign days	In HCW scenario, double the cost from baseline
	Volunteer Incentives	Cost	Campaign days	In volunteer scenario, double the cost from baseline
	Training	Cost	Training days	Increase by 50% from baseline to account for the additional team member
	Transportation	Cost	Per diems during the campaign	Increase by 50% from baseline to account for the additional team member
Intensified communication	Social Mobilization	Cost	Social Mobilization	Assumed 15% increase in cost, based on expert opinion

Table 2
Unit Cost Values. These unit costs were used in the Monte Carlo simulated cost model. Measles containing vaccine (MCV) and supply costs were used directly, based on UNICEF pricing tables, and total costs were calculated based on these fixed unit costs with specified wastage rates. The remaining cost categories were simulated, based on the mean unit cost listed here. See Supplement Table S1 for the unadjusted budget values from Gavi-funded campaign proposals, as originally approved.

Budget Line	Unit Cost	Range of Budget-Reported Values	Sample Size (N)	Planning Wastage Rate
MCV (M/MR)	\$2.37/\$6.56 per 10-dose vial [19]	–	–	15%
Reconstitution Syringe	\$0.40 per vial [20]	–	–	10%
Administration Syringe	\$0.37 per targeted person [20]	–	–	10%
Waste Box	\$0.494 per 100-capacity box [20]	–	–	10%
Freight Charges	11% of MCV price	2.4%–13.0%	9	–
HCW Resources	\$0.309 per dose	\$0.040–\$0.802	19	–
Volunteer Incentives	\$0.130 per dose	\$0.041–\$0.539	9	–
Training	\$0.119 per dose	\$0.040–\$0.302	21	–
Transportation	\$0.125 per dose	\$0.019–\$0.356	21	–
Social Mobilization	\$0.094 per dose	\$0.016–\$0.232	23	–

cost of a card reviewer, and a modest increase in the cost of social mobilization.

Depending on how a country would choose to implement a card review step, the task could be performed by either a healthcare worker (HCW) or by a trained volunteer. Either way, the additional person would increase the number of team members by half, adding one card reviewer for each vaccinator-recorder pair. This additional person would need to be trained and to have transportation during the campaign, so we have accounted for these costs as well. Table 1 summarizes the details of the cost model.

We spoke with in-country experts running immunization programs in low- and middle-income countries to get their perspectives on whether there would be additional cost implications from this policy. Based on these discussions, we opted not to include the impacts of a reduced number of planning doses on the cost of micro-planning, logistics, or waste management. While savings may be possible, we opted for a conservative approach and chose to exclude those potential savings from the model.

Measles vaccine and supply costs were considered fixed on a per-unit basis since these values are negotiated on the global market and prices are openly published. We calculated the cost of vaccine for both measles (M) and measles-rubella (MR) vaccine, since both are currently used in SIAs.

The baseline operational costs were based on historical Gavi-approved MCV campaign budgets. The summaries are publicly available on their website [12] and have consistent budget line item categories, which makes comparison and aggregation possible. We transferred the budget values from the published PDFs into Microsoft Excel for each approved MCV campaign budget that was published (ranging from 2012 and 2018) and inflated them to 2018 dollars using the World Bank's GDP inflator [14] (See Supplement Table S1).

Then we calculated the cost of each line item per targeted child in the campaign. We averaged the available non-zero budget line items to create the generic baseline budget.[1] The resulting unit costs are listed in Table 2.

Recognizing that there is uncertainty in the underlying costs of a campaign budget, we extended the Monte Carlo simulation also to sample the cost model parameters. We sampled from a normal distribution for each baseline unit cost, with a standard deviation calculated based on all countries that had more than one data point in the reference data, to represent the intra-country cost uncertainty.

The results were aggregated across 1000 simulation runs for each permutation of MCV2 and presentation rates. This resulted in a total of 1000 runs $\times$ 100 MCV2 rates $\times$ 100 card presentation rates = 10,000,000 simulation runs for analysis. For each simulation, we calculated the total financial impact of the card review policy.

In addition, we performed two scenario analyses in order to bound the range of possible outcomes.

The first scenario considered a declining card presentation rate for children above 1 year of age, which has been shown in some previous studies in low and middle income countries [15,16]. To model this, we had to simulate both the MCV coverage and card availability probabilities as age-dependent. We utilized a sigmoid function, which has a characteristic "S" curve shape, to model

[1] We excluded any budget line items that were below \$0.01 per person targeted from the calculation of the average cost. While some countries do not incur incremental cost to run a campaign (for example, by using existing health staff), there are still indirect costs incurred that these budgets would not capture. To counteract this, we made the conservative assumption to exclude near-zero values in order to limit the risk of underestimating the cost of introducing the card review step.

the underlying MCV coverage rate as a function of age. We used data from the most recent Demographics and Health Survey (DHS) from a representative sample of thirteen countries and applied a linear mixed-effects regression (LMER), controlling for country using a fixed effect, to the card retention by age and use this to simulate the decline in availability, conditional on age. This is the worst-case scenario from a cost-saving opportunity perspective.

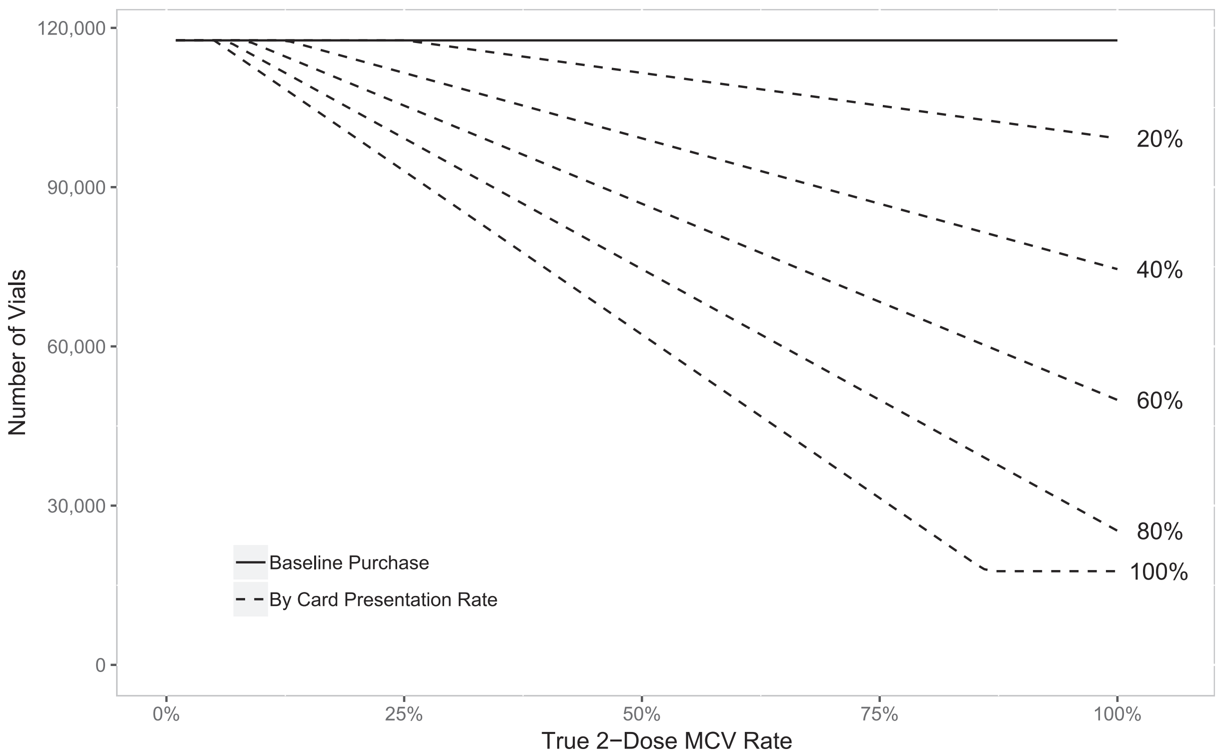

Fig. 1. MCV Vials Purchased Under Varying Conditions. The number of vials that would need to be purchased under varying levels of MCV2 coverage and card availability, for a target population of one million children. Each line represents and is labeled with the corresponding availability rate. As more children present a card, fewer would be vaccinated during the campaign and fewer vials would need to be purchased. The number of vials purchased is based on the size of the target population.

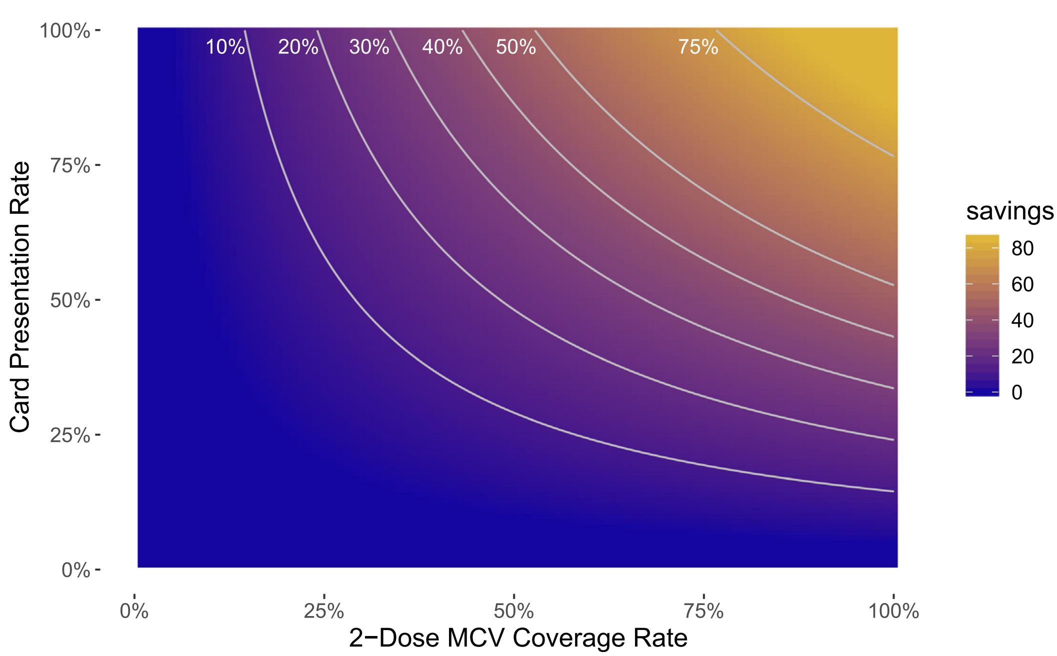

Fig. 2. Upper Limit on MCV and Supply Savings. The maximum possible MCV and supply savings, assuming that all children who have received and retained their home-based record also bring it with them to the vaccination campaign site. Maximum savings are calculated as a percentage savings relative to baseline (status quo) for MCV and administration supplies (syringes, waste boxes) only, and do not include the increased cost of labor and social mobilization due to the card review process. See Fig. 3 for the probability of savings for total costs.

The second scenario assumed a perfect correlation between children who have already received MCV2 through routine immunization and those who have vaccination records available. Though a perfect relationship is unlikely, a moderate level of correlation has been found previously in communities with moderate routine immuration coverage [17], though it has not always been the case [18]. This is the best-case scenario from a cost-saving opportunity perspective.

3. Results

The first step was to determine how many vials of MCV (and associated supplies) would need to be purchased in the card-review scenario, so that this could be compared to baseline. Applied to a hypothetical target population of 1,000,000 children, the number of vials purchased would be dependent on the MCV2 and the card availability rates. For example, a population with an 80% MCV2 rate and a 50% card presentation rate would purchase 115,000 vials under the baseline scenario and 79,350 vials under the card-review scenario. The 5% buffer rate ensures that adequate vials are purchased to cover heterogeneities in sub-populations, resulting in the flat line at low MCV2 rates in Fig. 1. The minimum purchase rate prevents the purchase from falling below 15% of baseline (see Fig. 1).

These purchase amounts were then used to estimate the savings from the subset of costs including MCV vials, syringes and waste boxes only, without considering any incremental operational costs. This serves as an upper bound on the possible savings opportunity (Fig. 2). At the lower end, even a modest combination of MCV2 and card presentation rates provides some potential opportunity for savings if those individuals with an HBR are able and willing to bring it with them to the campaign.

To inform the Monte Carlo simulation, we aggregated the Gavi-approved budgets for MCV campaigns and calculated the costs for the relevant budget categories per child targeted. This resulted in a per-child cost for campaign of $0.309 for human resources, $0.130 for volunteer incentives, $0.119 for training, $0.125 for transportation, and $0.094 for social mobilization. The MCV vials and supplies used in Gavi-funded campaigns are procured through UNICEF and their published 2018 prices are listed in Table 2.

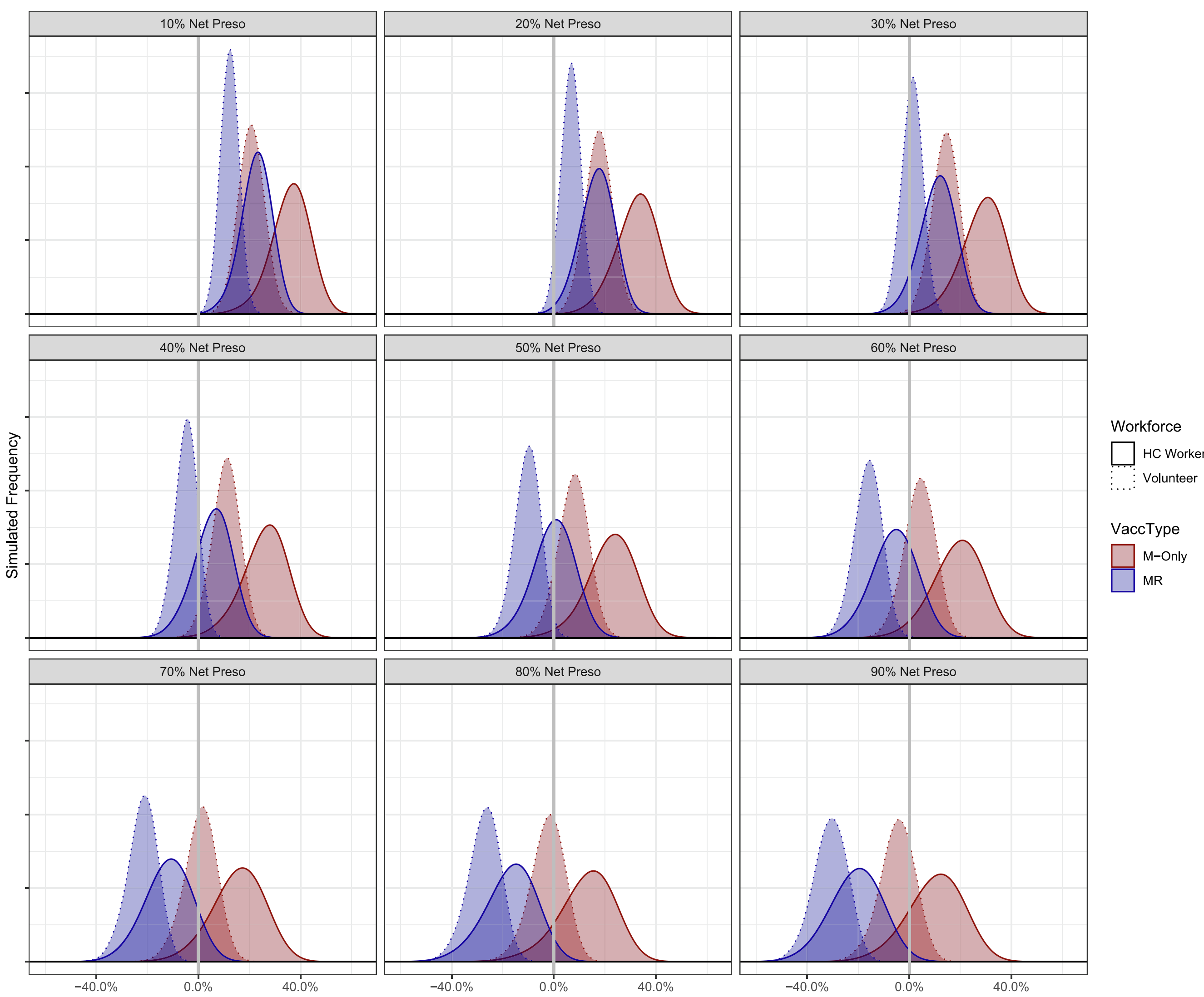

Fig. 3. Simulated Total Cost Impact. Net impact on total costs of various scenarios, by net presentation rate (joint probability of both MCV coverage and vaccination record availability). Solid line curves are for HCW card checker, dashed line curves are for a volunteer card checker. Red curves are from simulations assuming measles-only vaccine and the blue curves are from simulations assuming measles-rubella (MR) vaccine. Simulations to the right of zero represent an increase in total cost and simulations to the left represent a decrease in total cost (i.e. savings). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The results of the simulation indicate that there is a range of scenarios in which a card-review policy would be cost-saving. The situations where it is beneficial are when there is enough MCV and supply cost savings to offset the increase in staff, training, transport, and social mobilization costs.

Fig. 3 summarizes the simulated impact on total SIA costs. It is apparent from these results that there is uncertainty in the level of savings possible when considering total SIA costs. The net impact depends on the operational realities, which vaccine is being used in the campaign, and the anticipated net presentation rate. For example, in a geography with a low net presentation rate, it would be almost impossible to achieve savings. When comparing results, scenarios utilizing a volunteer to check cards are always more likely to results in savings, compared to those utilizing a healthcare worker. Additionally, scenarios in which an MR-vaccine was considered resulted in more savings than those in which a measles-only vaccine would be distributed. On aggregate, all four scenarios shift towards higher savings as the net presentation increases.

On aggregate, we can use the joint MCV2 and presentation rate (the two rates multiplied together) to examine the point at which cost savings would be likely. We would expect cost savings at any joint rate above the breakeven point.

The expected break-even point for utilizing a volunteer card reviewer during an MR vaccine campaign is a joint rate of 31.7%, with a 95% prediction interval of 19.3–45.3%. The break-even point for utilizing a healthcare worker (HCW) card reviewer during an MR vaccine campaign is somewhat higher at a joint rate of 49.2%, with a 95% prediction interval of 26.6–76.8%. The break-even point for a volunteer reviewer during a measles-only vaccine campaign is a joint rate of 72.6%, with a 95% prediction interval starting at 42.8% and including 100% (see Fig. 4).

The results of the scenario analysis on the number of doses that would be administered are presented in Fig. 5 (see Supplement Table S1 and Fig. S1 in supplement for details). In the scenario assuming a perfect correlation, the number of children vaccinated was somewhat lower than in the original model because there was a higher chance of any given individual having already received two doses and retaining their card as documentation, and thus not receiving an additional dose. For the scenario assuming a declining card availability rate, we found a reduction in DHS-reported card retention of 0.697% per month of age from 9 to 60 months based on historical DHS data. Applied to the simulation, the number of children vaccinated was higher than in the original model because older children were more likely to be vaccinated but also less likely to have documentation available to demonstrate this, so they were often revaccinated anyway. In some of the simulation runs with a declining availability rate, the number of children reached was greater than the doses purchased, which means that the standard 15% buffer stock was inadequate to support the policy and would need to be recalibrated based on local understanding of card availability.

4. Discussion

As far as the authors are aware, this is the first study to explicitly quantify the cost savings opportunity of a card-review strategy

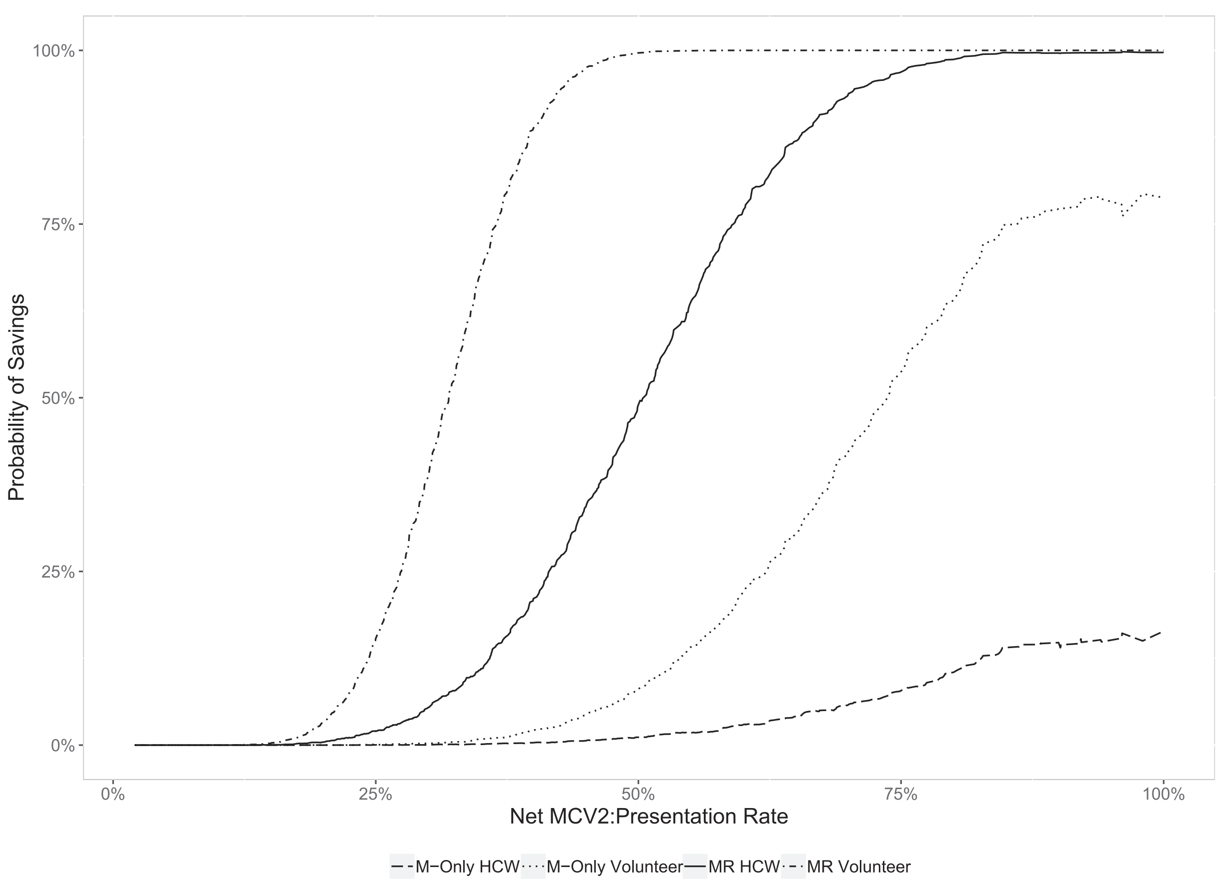

Fig. 4. Simulated Probability of a Savings Opportunity. The probability of achieving a cost savings by implementing a card review step during a vaccination campaign, relative to baseline total costs. Probability values are the portion of simulations that achieved at least a break-even cost impact (or achieved savings) under a card review scenario. M-Only scenarios represent measles-only vaccine; MR scenarios represent the use of measles-rubella vaccine. Healthcare worker (HCW) and volunteer worker cost scenarios are also presented.

as part of a supplementary immunization campaign. A country that is considering a card-review strategy could use the results of this study to estimate their potential cost savings, based on their MCV2 and card availability rates. This should be weighed against the work required to communicate the need to bring vaccination records to the campaign site, and whether the expected savings are worth the required administrative effort.

However, in countries with highly heterogenous populations, a sub-national approach may be necessary. Implementing a card review step in regions with high routine immunization coverage and good card availability may be highly cost-saving, but not in poorer performing areas. The best option in this situation may be to consider the card review step only in places where there is a significant anticipated benefit.

We note that one of the key assumptions in this analysis is that children attend the campaign with their vaccination records in hand and that previous doses will have been documented. While the HBR is the most common format for record keeping, there is a shift in some countries to using other forms of record keeping that may be more easily accessed, such as clinic-based or electronic medical records [21,22]. With more reliable and accessible documentation, the ability for countries to realize MCV savings using selective vaccination would improve.

The net savings on total SIA costs may be up to 40% in some places, but this is dependent on immunization record availability and operational choices. While there are not *currently* savings opportunity for many countries, if they are able to continue to improve vaccine coverage, the cost of unnecessarily vaccinating already-immune children with measles-rubella vaccine will be substantial. However, the cost savings can only be realized if immunization records are available (either clinic- or home-based) to substantiate previous vaccinations, and if the increased operational costs (labor, social mobilization, etc.) are not too large relative to the vaccine savings. Without work to reduce card stock-outs, ensure accuracy, adequate space for dose documentation, and improved card retention rate, this will not be possible.

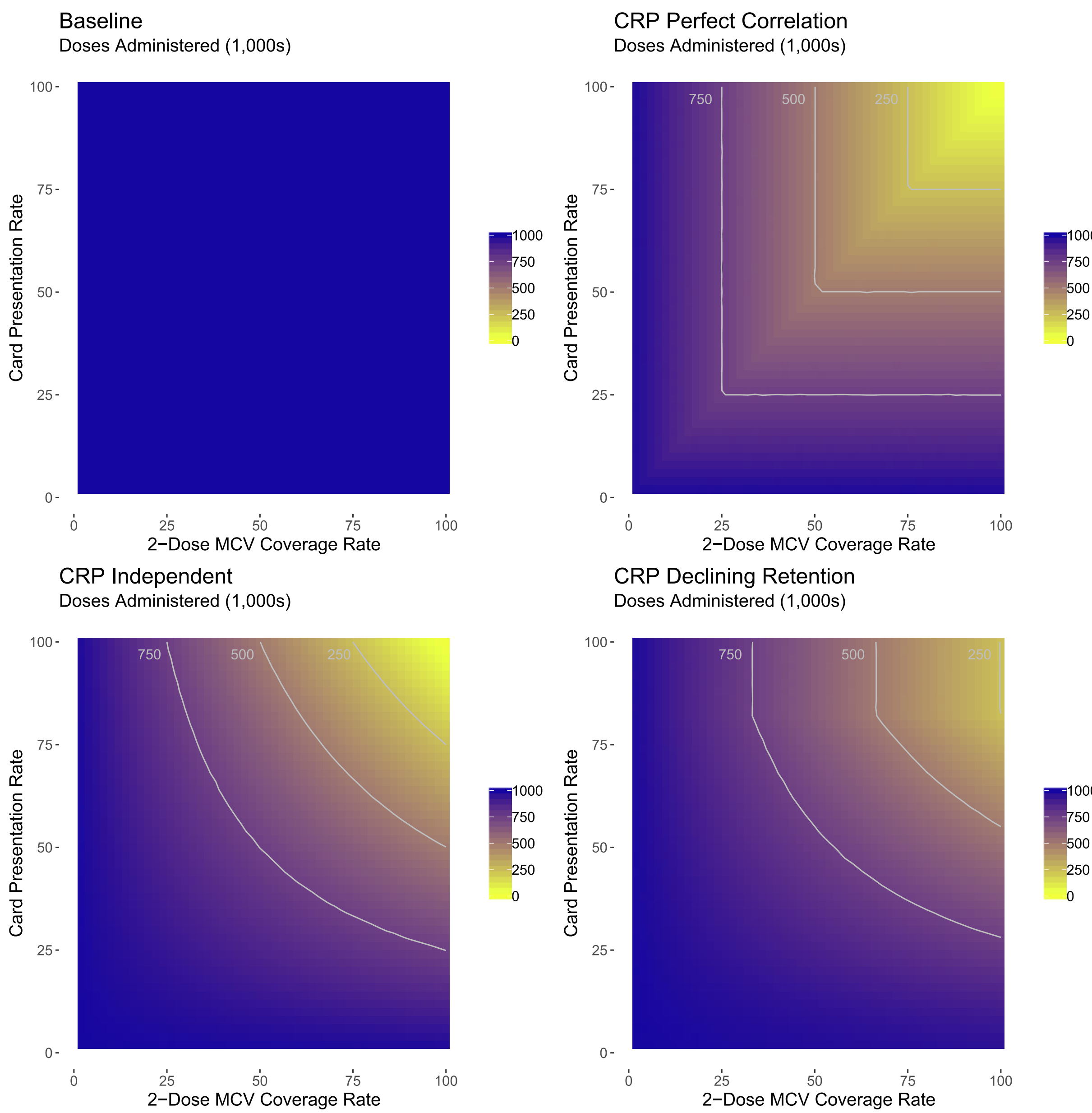

Fig. 5. Simulated Number of Doses. Simulated number of doses administered by scenario, for varying levels of MCV2 coverage and card presentation rates. For comparison, in the baseline (status quo) scenario, every individual in the target population would be vaccinated, for a total of one million doses administered. All values are in thousands of doses (for a maximum target population of one million). CRP: Card Review Policy.

This suggests the need for more countries to adopt the WHO's recommendation that all HBRs have space for vaccines received outside of the routine schedule [23]. In places where this is done, communities could be encouraged to bring their HBRs to every campaign so that doses given in campaigns can be accurately recorded. This would ensure that as children age, their HBRs would reflect their true vaccination history and the potential savings from a selective vaccination strategy would increase, especially in areas with frequent SIAs.

A card review step may have non-cost benefits as well, which present opportunities for further research. For one, if the card review step is performed by a trained individual, then they may be able to identify other late vaccinations and to engage with the caregiver about closing other immunity gaps. Identifying gaps may also allow for better reporting from the SIA about how many children are being reached with their first dose and coverage levels for other antigens, which could be valuable information for future SIA planning and for strengthening of the routine immunization system. Further, the implementation of a card review policy would reinforce a mindset for SIA planning teams to focus on reaching the previously unreached (high risk) populations. Additionally, asking caregivers to bring HBRs to SIAs may lead to more consistent documentation of both routine and SIA doses. This could benefit survey and coverage estimate accuracy, since full vaccination histories would be available for review.

However, there may be additional complexities for the post-campaign coverage survey as well. Eligibility for the survey is currently based on the child's age, but under a card-review scenario eligibility would also consider the child's HBR retention and previous vaccination. This would introduce survey complexity and may require increased sample size in order to obtain the same level of precision. While this may modestly increase monitoring and evaluation costs, these were less than 2% of total campaign costs in the referenced campaign budgets, and these costs would only increase in places with higher net presentation rates, which are the same places with high probability of savings.

The policy also has some risks that need to be considered, especially if a barrier, whether real or perceived, may reduce the likelihood that a caregiver will bring their child to the SIA. This may come in several forms, where a caregiver may perceive that the HBR is required before a vaccination will be given [24], they may expect to be criticized for not retaining the HBR, they may feel that attendance isn't "worth it" if the vaccine may not be given to their child, or there may become a perception of a "fast lane" for those who did not bring their cards to be reviewed.

There are some limitations to this analysis. One key consideration is whether it is politically feasible to purchase fewer supplies and to suggest that not every child will be vaccinated during the campaign. There are also operational considerations that limit the applicability of a selective vaccination strategy, including: the accuracy of sub-national data on coverage and card availability (so that vaccines and supplies can be properly distributed), the availability of a skilled workforce to review vaccination cards, and the feasibility or repurposing unopened MCV vials.

A selective vaccination policy based on the introduction of a card review step may be cost saving in settings where there is both adequate MCV2 coverage and vaccination record availability. This savings opportunity is valuable if a country is making decisions about health investments in the context of limited funding and if the cost savings can be spent on an alternative intervention that would otherwise not be possible.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contributions

BH acquired the data, conducted the analyses, and drafted the manuscript. AD provided critical framing and contextual relevance for the analysis. KM oversaw the project and provided critical review of the interpretation of results and discussion. All authors have reviewed and approved this manuscript.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2019.08.049.

References

[1] The World Bank. Immunization, measles (% of children ages 12-23 months) | Data 2017. <https://data.worldbank.org/indicator/SH.IMM.MEAS> [accessed November 30, 2018].
[2] Oh DH, Dabbagh A, Goodson JL, Strebel PM, Thapa S, Giri JN, et al. Measles vaccines: WHO position paper - April 2017. Wkly Epidemiol Rec 2016;92:205–28.
[3] WHO|Global Vaccine Action Plan 2011-2020. WHO; 2017.
[4] Simons E, Mort M, Dabbagh A, Strebel P. Wolfson L. Strategic planning for measles control: using data to inform optimal vaccination strategies. J Infect Dis 2011;204.. https://doi.org/10.1093/infdis/jir095.
[5] Portnoy A, Jit M, Helleringer S, Verguet S. Impact of measles supplementary immunization activities on reaching children missed by routine programs 2018;36(1):170–8.
[6] Asturias EJ, Bandyopadhyay AS, Self S, Rivera L, Saez-Llorens X, Lopez E, et al. Humoral and intestinal immunity induced by new schedules of bivalent oral poliovirus vaccine and one or two doses of inactivated poliovirus vaccine in Latin American infants: an open-label randomised controlled trial. Lancet 2016;388:158–69. https://doi.org/10.1016/S0140-6736(16)00703-0.
[7] Grais RF, Conlan AJK, Ferrari MJ, Djibo A, Le Menach A, Bjørnstad ON, et al. Time is of the essence: exploring a measles outbreak response vaccination in Niamey, Niger. J R Soc Interface 2008;5:67–74. https://doi.org/10.1098/rsif.2007.1038.
[8] Cairns KL, Perry RT, Ryman TK, Nandy RK, Grais RF. Should outbreak response immunization be recommended for measles outbreaks in middle- and low-income countries? An update. J Infect Dis 2011;204. https://doi.org/10.1093/infdis/jir072.
[9] Centers for Disease Control and Prevention. Measles. Epidemiol Prev Vaccine-Preventable Dis 13th Ed; 2015. p. 209–29.
[10] Minetti A, Hurtado N, Grais RF, Ferrari M. Reaching hard-to-reach individuals: Nonselective versus targeted outbreak response vaccination for measles. Am J Epidemiol 2014;179:245–51. https://doi.org/10.1093/aje/kwt236.
[11] WHO. Planning and Implementing High Quality Supplementary Immunization Activities for Measles-Rubella and other Injectable Vaccines FIELD GUIDE. World Heal Organ 2012:1–155.
[12] Gavi TVA. Country Hub n.d. <https://www.gavi.org/country/> [accessed June 1, 2018].
[13] Team RC. R: A Language and Enviornment for Statistical Computing; 2018.
[14] The World Bank. GDP Deflator; n.d. <https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS> [accessed June 1, 2018].
[15] Phari DP, Bastola P, Paudel R. Factors affecting retention of child health card in a rural area. J Nepal Health Res Counc 2011;9:154–8.
[16] Sheikh S Sadiq, Sheikh S Asad Ali Sana Sadiq, Asad Ali S. Predictors of Vaccination Card Retention in Children 12-59 months old in Karachi, Pakistan. Oman Med J 2014;29(3):190–3. https://doi.org/10.5001/omj.2014.47.
[17] Bhandari R, Adhikari M, Khanal V. Factors associated with child health card holding among mothers of Western Rural Nepal: a cross sectional community based study. Int J Child Heal Nutr 2013. https://doi.org/10.6000/1929-4247.2013.02.02.6.

[18] Kawakatsu Y, Sugishita T, Oruenjo K, Wakhule S, Kibosia K, Were E, et al. Effectiveness of and factors related to possession of a mother and child health handbook: an analysis using propensity score matching. Heal Educ Res 2015;30:935–46.
[19] UNICEF Supply Division. MR Pricing List UNICEF 2018; 2018.
[20] UNICEF Supply Division. Auto-disable syringes, re-use prevention syringes and safety boxes price data. Suppl Logist 2016:462.
[21] King C, Hall J, Banda M, Beard J, Bird J, Kazembe P, et al. Electronic data capture in a rural African setting: evaluating experiences with different systems in Malawi. Glob Health Action 2014;7:25878. https://doi.org/10.3402/gha.v7.25878.
[22] Kamadjeu R, Tapang E, Moluh R. Designing and implementing an electronic health record system in primary care practice in sub-Saharan Africa: a case study from Cameroon. J Innov Heal Inform 2005;13:179–86. https://doi.org/10.14236/jhi.v13i3.595.
[23] WHO. Practical guide for the design, use and promotion of home-based records in immunization programmes; 2015.
[24] Brown DW, Tabu C, Sergon K, Shendale S, Mugoya I, Machekanyanga Z, et al. Home-based record (HBR) ownership and use of HBR recording fields in selected Kenyan communities: Results from the Kenya Missed Opportunities for Vaccination Assessment; 2018. doi:10.1371/journal.pone.0201538.