Article:
Rao, Megha, MOHAN, SAKSHI, Mayora, Chrispus et al. (2026) Redesigning national health service delivery: the case for community-based health service providers in Uganda. Health Economics, Policy and Law. ISSN: 1744-1331

https://doi.org/10.1017/S1744133126100644

Health Economics, Policy and Law (2026), page 1 of 20
doi:10.1017/S1744133126100644

HEALTH ECONOMICS, POLICY and LAW

ARTICLE

Redesigning national health service delivery: the case for community-based health service providers in Uganda

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(Received 29 September 2025 UTC; revised 29 May 2026 UTC; accepted 15 June 2026 UTC)

Abstract
Generating evidence to guide investments in new service delivery platforms remains a major challenge. We applied a linear constrained optimisation model, ex ante, to estimate the potential health impact and trade-offs of integrating community-based providers (CBPs) into Uganda's essential healthcare package. Specifically, we compared a facility-only delivery strategy with an integrated strategy that included Village Health Teams (VHTs) and medicine retailers. Outcomes included potential expansion of the optimal service package, additional net disability-adjusted life years averted, average cost-effectiveness, and maximum cost-effective investment per provider. Integrating CBPs could avert an additional 4.7 million net disability-adjusted life years and expand Uganda's optimal health package by 25 interventions compared to the facility-only strategy. VHTs achieved health gains at $42 per net DALY averted and remained cost-effective at an investment of up to $3,423 per provider; medicine retailers remained cost-effective up to $19,792 per provider. Although current policies restrict CBP utilisation, results indicate substantial potential for health system strengthening. Constrained optimisation provides a systematic approach to quantify the value of new delivery platforms. Our findings provide an evidence-based roadmap for integrating CBPs in Uganda, while the adaptable model itself serves as a replicable tool to inform similar analyses in other settings.

Keywords: community-based providers; constrained optimisation; health system strengthening; opportunity costs; resource allocation

1. Introduction

While conventional CEA is a cornerstone of health economics, its application is limited in contexts with multiple, short term, binding resource constraints (Hauck *et al.*, 2016; van Baal *et al.*, 2018). Constrained optimisation models address this by identifying the health-maximising portfolio of interventions, subject to a range of system-wide constraints (Stinnett and Paltiel, 1996), thereby explicitly capturing the trade-offs and opportunity costs associated with different resource allocation decisions. This broader, system-oriented perspective is especially valuable given that health interventions are delivered through shared service delivery 'platforms' – the underlying systems of human and capital resources that support multiple services (Watkins *et al.*, 2017). Global health priority-setting resources, such as Disease Control Priorities (Jamison *et al.*, 2017), support this thinking by encouraging countries to invest directly in strengthening these platforms as part of broader efforts to improve service delivery. Constrained optimisation can model such investments, and recent applications have quantified the potential health benefits of relaxing capacity constraints within *existing* platforms, as demonstrated by Mohan *et al.*, 2023 in Uganda.

A distinct and less explored application of constrained optimisation, however, is its *ex ante* use in evaluating the potential health impact of introducing entirely *new* platforms. Such a platform could be either new physical infrastructure or major organisational reforms that fundamentally reconfigures how health system resources are used (Hauck *et al.*, 2019). Making the case for such decisions presents a significant evidential challenge. In Uganda, for example, efforts to scale up community-based healthcare nationwide have struggled to secure long-term government commitment. This is partly due to the absence of comprehensive, system-wide value-for-money assessments (Donovan *et al.*, 2025) that could quantify their broader impact and make a stronger case for sustained support. We apply a constrained optimisation approach to address this challenge, demonstrating how it can be used to quantify the added value of integrating community-based providers (CBPs), specifically Village Health Team (VHT) and medicine retailers, as a new service delivery platform within Uganda's national health system. To do this, our analysis models the maximum potential health gains achievable by the health system under two strategies: one without CBPs (the baseline strategy) and one with CBPs (the integration strategy). The difference between the two outcomes isolates the health benefit attributable to the new platform, allowing us to answer a pressing policy question: does integrating CBPs improve population health?

2. Background

In Uganda, two groups of community-based health providers play a major role in service delivery and show potential for integration in Uganda's existing health system (Ssengooba *et al.*, forthcoming). The first is the government-recognised cadre of VHTs, established in 2002 (Ministry of Health, 2010). The second is the medicine retail sector (MRS), largely made up of retail pharmacies and drug shops (Hutchinson *et al.*, 2025).

VHTs are a collective cadre of volunteer lay workers assigned to a specific village who receive basic training and act as critical intermediaries between formal health facilities and local communities, particularly in remote areas. Within this cadre, curative health services are provided by individual workers to each person in need of care, rather than being delivered collectively as a team. Despite their wide reach, VHTs are currently engaged in a fragmented, disease-specific manner in Uganda – primarily supporting programmes related to neglected tropical diseases (NTDs), maternal and child health, HIV/AIDS, tuberculosis (TB), malaria, and outbreak response. Consequently, their impact has been evaluated in a similarly siloed manner (Vaughan *et al.*, 2015), with limited evidence on their broader value across the health system (Donovan *et al.*, 2025).

Similarly, Uganda's MRS plays a key role in treating common illnesses and providing essential medicines, particularly where public health services are limited. Although there have been successful efforts (eg, retail pharmacies serving as ART refill points) to engage the MRS in expanding public health access (Awor *et al.*, 2014; Kitutu *et al.*, 2014; Mayora *et al.*, 2018; Mbonye *et al.*, 2015), the sector remains largely excluded from national health planning (Hutchinson *et al.*, 2022, 2023). While their formal integration in healthcare through public reimbursement and establishment of referral mechanisms is being considered, evidence quantifying its potential public health value remains scarce.

Our paper examines the potential added value of VHTs and medicine retailers – specifically retail pharmacies and drug shops – to support the delivery of Uganda's National Essential Health Care Package (UNEHCP) (Ministry of Health, 2024a). The UNEHCP defines a set of essential health services and programmes that Uganda's public health system is expected to deliver universally to its entire population (Ministry of Health, 2024a). As such, it provides an opportunity for evaluating the added value of CBPs as a new platform in delivering interventions nationally in coordination with existing facility-based structures. Our analysis explores how integrating CBPs influences the optimal service mix, population health outcomes, and overall resource use. Finally, we assess the cost-effectiveness of integrating these providers and Uganda's ability to invest in them given the value of other potential uses of health care resources.

3. Methods

3.1. Essential healthcare package design using constrained optimisation model

Mohan *et al.* (2023) used a linear constrained optimisation approach to support the design of UNEHCP by identifying the set of services to include in the package for the current year by maximising population health benefits (lifetime health gains for the impacted cohort in that year) subject to annual constraints on the consumables budget and facility-based providers. This original configuration represents our baseline strategy: a health system model that relies exclusively on facility-based service delivery[1] and excludes alternative delivery platforms such as VHTs and medicine retailers.

Mathematically, this can be represented as -

$$maximize \sum_i x_i n_i v_i \qquad \ldots \textit{Objective (1a)}$$

Subject to:

$$s.t. \sum_i x_i n_i c_i \leq B \qquad \ldots \textit{Drugs and consumables budget constraint (2a)}$$

$$s.t. \sum_i x_i n_i l_{ij} \leq L_j, \forall jJ \qquad \ldots \textit{Health worker time constraints (3a)}$$

$$0 \leq x_i \leq 1 \; \forall \; i \qquad \ldots \textit{Feasible coverage constraint (4a)}$$

Where-

$x_i =$ proportion of eligible cases receiving the intervention i (decision variable)
$n_i =$ number of eligible cases for the intervention i
$v_i =$ net DALYs averted per case treated with intervention i
$c_i =$ Per-case drugs and consumables cost of intervention i
$B =$ Total annual consumables budget
$l_{ij} =$ Time required of cadre j per case treated with intervention i
$L_j =$ Total time available of cadre j
J is the set of all relevant cadres (limited to facility-based cadres in this strategy)

We then expand the model to include both community- and facility-based providers, making use of the broader health workforce available in Uganda. This configuration is referred to as the CBP integration strategy[2]: a health system model that incorporates alternative delivery platforms such as VHTs and medicine retailers alongside facility-based service delivery. Because the

[1] All cases are fully managed by the facility-based staff.

[2] Even when alternative platforms (eg, CBPs) are used, facility-based staff may remain partially involved in managing the cases. This is reflected in the platform-specific time parameters $l_{i,j,w}$, which capture the reduced time required from facility staff when cases are delivered through the new platforms.

optimisation model maximises population health gains under fixed resource constraints, it is designed to endogenously reallocate resources freed up by shifting cases to CBPs toward delivering additional interventions or expanding coverage of existing ones within the package.

It can be expressed mathematically as follows:

$$maximize \sum_i \sum_{w \in W} x_{i,w} n_i v_i \qquad \ldots \textbf{\textit{Objective (1b)}}$$

Subject to:

$$s.t. \sum_i \sum_{w \in W} x_{i,w} n_i c_i \le B \qquad \ldots \textbf{\textit{Drugs and consumables budget constraint (2b)}}$$

$$s.t. \sum_i \sum_{w \in W} x_{i,w} n_i l_{i,j,w} \le L_j, \forall j J \qquad \ldots \textbf{\textit{Health worker time constraints (3b)}}$$

$$0 \le x_{i,w} \le u_{i,w} \quad \forall\ i\ \varepsilon\ I_w, \forall\ w\ \varepsilon\ W \qquad \ldots \textbf{\textit{Community-based delivery constraints (4b)}}$$

$$\sum_{w \in W} x_{i,w} = x_i;\ 0 \le x_i \le 1\ \forall\ i \qquad \ldots \textbf{\textit{Feasible coverage constraint (5b)}}$$

Where

J is now the expanded set of all relevant cadres (includes CBPs)

W = Set of delivery platforms considered in the model (eg, facility, VHTs, and medicine retailer)

w = Specific platform

$x_{i,w}$ = proportion of eligible cases receiving the intervention i through the platform w

x_i = proportion of eligible cases receiving the intervention i across all platforms

$l_{i,j,w}$ = time required of cadre j per case treated with intervention i via platform w

c_i = Per-case drugs and consumables cost of intervention i (assumed platform-invariant[3])

n_i = number of eligible cases for the intervention i

v_i = net DALYs averted per case treated with intervention i

I_w = Set of interventions that can feasibly be delivered via platform w

$u_{i,w}$ = Maximum case constraints, or the maximum percentages of cases that can be supported by the platform of type w.

Ideally, a constrained optimisation model would incorporate *all* supply and demand constraints to identify the package of interventions which maximises *total* DALYs averted of the package of interventions. In practice, however, the extensive data on resource productivity and input requirements needed to operationalise such a comprehensive model are rarely available. To address this challenge, our model explicitly accounts for the two supply-side constraints in Uganda and incorporates *net* DALYs averted as the measure of population health benefits in the objective function, to implicitly capture the effect of other constraints. This metric captures the population health benefit of an intervention after accounting for the health opportunity cost, that is, the DALYs that would have been averted if the same resources were instead allocated to other services at the margin. We calculate this opportunity cost of implementing each intervention as its cost divided by the cost-effectiveness threshold (CET) of $165 per DALY averted, which reflects the marginal productivity of health spending in Uganda (Lomas *et al.*, 2022). By using net DALYs averted, our model not only implicitly captures the effects of unmodeled constraints during the modelled year but also the future health foregone due to long-term downstream costs, providing a more comprehensive measure of an intervention's overall value (Thokala *et al.*, 2018).

The model optimises the proportion of eligible cases covered by each health intervention (see decision variable) for each platform, allowing interventions to lie somewhere between exclusion from the UNEHCP (0 per cent) and inclusion at full coverage (100 per cent). It is subject to two primary constraints: the total budget for consumables and the availability of health workers.

The consumables budget includes both government and donor funding for public and private not-for-profit health commodities. The health workforce constraint can be modelled to include only facility-based providers, or both facility-based and CBPs. Facility-based providers include doctors, nurses, pharmacists, laboratory staff, mental health staff, nutritionists, and radiography staff from public and private not-for-profit sectors. CBPs include VHT members and medicine retailers (retail pharmacies and drug shops).

Our new platform(s) – VHTs and medicine retailers have broad potential to contribute across disease areas. However, in the model, their involvement is restricted to specific interventions within those areas that align with Uganda's clinical and regulatory guidelines and are considered locally feasible (Equation 4b). Each intervention involves multiple tasks requiring time contributions from various health worker cadres. Medicine retailers are assumed to support drug dispensing through task-shifting, fully substituting for facility pharmacists and removing the need for their time for cases administered by them. Whereas, VHTs are assumed to participate in task-sharing, working alongside facility staff to deliver services. This means that introducing VHTs doesn't fully replace facility-based health workers; rather, VHTs take on specific subset of tasks within their defined scope of practice. As a result, the time required from facility-based providers is reduced, but not eliminated. Further, to account for real-world demand and supply constraints faced by VHTs and medicine retailers in Uganda – including service delivery challenges, provider capacity and deployment, and other contextual factors – the model includes a constraint (see Equation 4b) that sets an upper limit on the percentage of cases they can contribute to, with this maximum percentage varying by intervention. This upper limit was informed by the share of the population seeking care from these providers using national health surveys and local expert input. Since separately parameterising demand- and supply-side constraints was not feasible given data limitations, this served as a pragmatic proxy for their combined effect, making the analysis contextually grounded. This approach is consistent with the concept of maximum feasible coverage used in established methodologies, including (Ochalek *et al.*, 2018) and the OneHealth Tool (OHT) (Avenir Health, 2016a). Interventions involving VHTs and medicine retailers, along with the maximum case percentages they can support, are detailed in online Appendix, Table A1.

We also include additional constraints to capture relationships among interventions – substitutable interventions, where only one needs to be delivered to avoid duplication (eg, 1-month daily vs. 3-month weekly isoniazid preventive therapy for HIV-positive individuals); complementary interventions, where delivery of the second depends on coverage of the first (post-abortion case management following an abortion); and care cascade interventions, which must be delivered together as a package (eg, HIV testing and first-line ART) (see online Appendix, Table A5–8).

The analysis was performed using the linear programming package called 'lpSolve' on R. The analysis script and input data are freely available on GitHub.

3.2. Data sources for model parameters

3.2.1. Cost-effectiveness of interventions

This study considered 367 interventions aligned with Uganda's Ministry of Health's Strategic Plan 2020/21–2024/25 (Ministry of Health, 2021a). Of these, 194 with complete data were included in the constrained optimisation analysis (see online Appendix, Table A1). DALYs averted and full healthcare costs per case were primarily drawn from 2021 WHO-CHOICE studies (Bertram *et al.*, 2021; Ralaidovy *et al.*, 2021; Stenberg *et al.*, 2021 and Eregata *et al.*, 2021). These studies are preferred for using a 'null' scenario (represents the option of offering no care or active treatment for the target population) as a common comparator, allowing simultaneous evaluation of multiple alternatives for the optimisation model. As these sources do not provide Uganda-specific estimates, we assumed that the per-case estimates from the source country also apply to Uganda. Where data was unavailable, we used estimates from the Global Health Cost-Effectiveness Registry (Center for the Evaluation of Value and Risk in Health, 2022 and Mohan *et al.*, 2023). The reference year for costs is 2023.

3.2.2. Eligible cases

Eligible cases in Uganda receiving the intervention were drawn from epidemiological reports and surveys (Ministry of Health, 2020; UNAIDS, 2022; World Health Organisation, 2024) and the GBD 2021 study (Institute for Health Metrics and Evaluation (IHME), 2024), with any gaps filled using OHT estimates (Avenir Health, 2016a) (online Appendix, Table A1).

3.2.3. Consumables cost

Consumable costs were drawn chiefly from the OHT and supplemented by relevant costing and cost-effectiveness studies, with gaps filled by a recent Malawi costing exercise (Connolly *et al.*, 2024). The total consumables budget was sourced from the Ugandan Ministry of Health's 2024/25 Integrated Quantification for Essential Medicines and Health Supplies factsheet (Ministry of Health, 2024b). Costs from 2024/25 were adjusted to 2023/24 and expressed in USD (see online Appendix, Table A1&4).

3.2.4. Facility-based provider time required and available, and workforce capacity.

Due to limited Uganda-specific data, facility-based provider's patient-facing time required per case was estimated using Malawi's 2022–2025 Workforce Optimisation Model (WFOM) (Ministry of Health, 2023a), assuming equivalent time requirements in Uganda. This captured the minutes required to provide common health services based on time–motion observations and expert opinion. For interventions not included in WFOM, input assumptions from WHO-CHOICE 2021 and the OHT manual (Avenir Health, 2016b) were used. Annual patient-facing time available was based on expert opinion. Total number of facility-based workers was drawn from Uganda's 2023 Health Labour Market Analysis and 2019 Human Resource Audit report (Ministry of Health, 2021b; World Health Organisation, 2023). For details, see online Appendix, Table A1–3.

3.2.5. Interventions and maximum cases involving VHTs and medicine retailers

Interventions that can be supported by VHTs, and medicine retailers were identified through a review of Uganda's 2023 Clinical Guidelines (Ministry of Health, 2023b) and the OHT manual (Avenir Health, 2016b), then validated with in-country experts. The maximum proportion of cases that can be supported by VHTs and medicine retailers was determined through consultations, population-based health surveys (Uganda Bureau of Statistics, 2023; Uganda National Malaria Control Division (NMCD) *et al.*, 2020) and published literature (Gebresillassie *et al.*, 2023) (see online Appendix, Table A1).

3.2.6. VHT and medicine retailer time required and available, and workforce capacity.

VHT's patient-facing time required per case was derived using expert input from academic partners with extensive field and policy experience in Uganda, along with relevant literature. Total patient-facing time available was based on UNEST study (Ekirapa-Kiracho *et al.*, 2017), and other time and motion data (Aron *et al.*, 2023; Tani *et al.*, 2016). Total VHT numbers were sourced from Community Health Roadmap 2021 (UNICEF, 2021). Medicine retailer's patient-facing time required per case was assumed to be the same as facility-based pharmacists due to limited data. Total patient-facing time available was informed by expert opinion. Total number of medicine retailers came from the National Drug Authority (NDA) registry (Government of Uganda, 2024a, 2024b), which lists licensed retail pharmacies (urban) and drug shops (rural); unregistered outlets were excluded. One retailer (equivalent to 1 CBP) per rural drug shop and two per urban retail pharmacy (to reflect longer hours) were assumed (see online Appendix, Table A2–3).

Box 1: Illustrative examples of each approach

VHT task-sharing approach: This refers to the redistribution of tasks among health workforce teams. Unlike task-shifting where tasks are reassigned, here, additional cadres are able to take on identified tasks as part of the delivery of interventions based on their skill set. Consider an intervention that initially requires 50 minutes of facility-based staff time – 20 minutes from a doctor (or $\frac{2}{5}$ of the total) and 30 minutes from a nurse (or $\frac{3}{5}$ of the total). Suppose a VHT contributes 10 minutes of patient-facing time. In the absence of evidence on how VHT time substitutes for facility-based staff time, we make the following simplifying assumptions: (1) The total time required to deliver the intervention remains fixed at 50 minutes, and (2) VHT time is a perfect substitute for facility-based staff time. Under these assumptions, the facility-based time is reduced to 40 minutes, which is then redistributed between the doctor and nurse according to the original proportions – resulting in 16 minutes for the doctor and 24 minutes for the nurse.

Medicine Retailer Task Shifting Approach: Consider an intervention that requires 5 minutes of time from a facility-based pharmacist. We assume that medicine retailers are a perfect substitute for facility-based pharmacists – delivering the same task with equivalent efficiency and quality. Under this assumption, medicine retailers can perform the intervention in the same amount of time – 5 minutes – with no additional time required.

3.3. Strategies

The model enables separate and combined integration of VHTs and medicine retailers as service delivery platforms. Three strategies were compared against the baseline: standalone VHT integration, standalone medicine retailer integration, and joint integration of both. Outcome measures included the additional interventions delivered, the additional net DALYs averted, and the percentage of available VHTs and medicine retailers utilised.

3.3.1. Standalone integration of VHT

This strategy models the integration of VHTs in service delivery as the new platform. The platform operates through a task-sharing mechanism (Schaefer, 2015), where VHTs assume responsibility for specific tasks previously performed by more highly qualified, facility-based health workers up to a defined maximum percentage of cases (see Box 1).

3.3.2. Standalone integration of medicine retailers

This strategy models the integration of medicine retailers as the new platform. The platform operates through a task-shifting mechanism, where medicine retailers substitute for facility-based pharmacists in dispensing medicines for relevant interventions and up to a defined maximum percentage of cases (see Box 1).

3.3.3. Joint integration of VHTs and medicine retailers

This strategy models the integration of both VHTs and medicine retailers as the new platform. The platform operates through the mechanisms described in the standalone strategies, simultaneously.

3.4. Extensions

3.4.1. Allowing for markup on consumables for medicine retailers

To incentivise their participation, we assume that contracted medicine retailers are reimbursed by the government at a rate higher than the drug's cost by adding a 25 per cent markup (ie, difference between purchase and retail price) to the consumables cost per case for interventions and cases supported by medicine retailers.

3.4.2. Removing maximum case constraints for VHTs and medicine retailers

To assess whether alleviating the demand and supply-side constraints faced by the platform yields additional health benefits, we run the standalone and joint integration strategies without an upper limit on the percentage of cases VHTs and medicine retailers can support – allowing each to be involved in the delivery of 100 per cent of total eligible cases if capacity allows. This is analysed both without and with the inclusion of markups on consumables.

3.5. Value per provider and average productivity

We estimate the maximum total cost per VHT and medicine retailer that would remain cost-effective for delivering the optimal package in the current year, based on the lifetime health benefits generated for those treated during that year. This is calculated by dividing the additional net DALYs averted from their standalone integration (relative to the baseline) by their total number available in Uganda, assuming full utilisation of the existing workforce in delivering the optimal package, and then multiplying by Uganda's CET. The estimate includes all components of delivery costs, including provider payments.

Let

C_j be the maximum total cost per provider

$$C_j = \frac{NDA_{j,integration} - NDA_{baseline}}{N_j} \times CET_{Uganda}$$

Where:

- j includes only VHT and medicine retailer
- $NDA_{j,\ integration}$ is the Net DALYs averted under the standalone integration strategy involving provider type j
- $NDA_{baseline}$ is the Net DALYs averted under the baseline strategy
- $N =$ Total number of provider type j available

We also estimate the average productivity of VHTs in Uganda, expressed as net DALYs averted per dollar spent on their annual salaries. The reciprocal of this value represents the average cost-effectiveness ratio (ACER) – measured as the average cost per net DALY averted. VHTs would be considered cost-effective if their ACER is below Uganda's CET. Comparable estimates could not be produced for medicine retailers, as they do not receive formal remuneration.

Let

$P_j =$ Average productivity of health worker cadre j

$S_j =$ Average annual salary for a worker in cadre j.

$N_j =$ Total number of workers in cadre j.

For facility-based staff who are already part of the baseline strategy:

$$P_j = \frac{NDA_{baseline} - NDA_{without\ j}}{S_j \times N_j}$$

$$\boldsymbol{ACER_j = 1/P_j}$$

For VHTs who are not present in the baseline, but are introduced in the integrated strategy

$$P_{VHT} = \frac{NDA_{VHT,integration} - NDA_{baseline}}{S_{VHT} \times N_{VHT}}$$

$$\boldsymbol{ACER_{VHT} = 1/P_{VHT}}$$

Where

- j includes all facility-based cadres
- $NDA_{baseline}$ is the Net DALYs averted with all cadres present.
- $NDA_{without\ j}$ is the Net DALYs averted if cadre j is removed from the baseline.
- $NDA_{VHT,\ integration}$ is the Net DALYs averted under the standalone VHT integration strategy

4. Results

4.1. Baseline strategy

Our baseline strategy, limited to facility-based service delivery, identifies an optimal package consisting of 38 interventions, estimated to avert 111 million net DALYs.

4.2. Impact of integrating VHTs and medicine retailers

Integrating CBPs demonstrates potential to expand the optimal intervention package and increase net DALYs averted. Compared to the baseline (see Table 1), standalone integration of VHTs expands the package by 6 interventions (total 44), yielding an additional 2.9 million net DALYs averted, while requiring approximately 6.6 per cent of available VHTs. Standalone integration of medicine retailers results in a larger package expansion by 22 interventions relative to the baseline (total 60); however, it yields a smaller health impact than VHTs, with additional 1.8 million net DALYs averted, while requiring about 5 per cent of available medicine retailers. The greatest gains were observed with the joint integration of both VHTs and medicine retailers, which expanded the package by 25 interventions (total 63) and increased net DALYs averted by approximately 4.7 million, requiring 6.8 per cent of VHTs and 3.8 per cent of medicine retailers available. Online Appendix, Tables A9–12 provides a full list of interventions included in the optimal package as well as the breakdown of case distributions for all strategies.

Results were further analysed by disease programme, including HIV and other sexually transmitted infections (STIs), integrated management of childhood illnesses (IMCI), malaria, mental health, non-communicable diseases (NCDs), NTDs, nutrition, reproductive, maternal, neonatal and child health (RMNCH), TB, vaccine preventable diseases, and water, sanitation, and hygiene (WASH) interventions. Figure 1a–d illustrates how resource use varies across these programmes under each strategy. Standalone integration of VHTs, resulted in an increase in DALYs averted, primarily in HIV/STIs, malaria, and RMNCH programmes. Similarly, standalone integration of medicine retailers increased DALYs averted, particularly in programmes such as HIV/STIs, malaria, RMNCH, IMCI, and nutrition. Joint integration also contributed to an increased DALYs averted in these same disease programmes. Table 2 lists interventions included in each strategy.

4.3. Extensions

4.3.1. Allowing for markup on consumables for medicine retailers

Table 1 shows that though applying markups to consumables provided by medicine retailers has minimal effect on the package size and the net DALYs averted, it results in a reduced reliance on medicine retailers in the delivery of the optimal package. See online Appendix, Tables A13–14.

4.3.2. Removing maximum case constraints for VHTs and medicine retailers

Table 3 highlights that without maximum case constraints, integrating VHTs expands the package by 7 additional interventions (total 45) and averts 6.5 million more net DALYs compared to the

Table 1. Summary of results from the constrained optimisation model

	Baseline (only facility-based workers)	Standalone integration of VHTs	Standalone integration of medicine retailers	Joint integration of VHTs and medicine retailers	Standalone integration of medicine retailers	Joint integration of VHTs and medicine retailers
	Without markup				With markup	
Interventions in the optimal package	38	44	60	63	60	62
Net DALYs averted	111,154,883	114,085,489	112,967,702	115,850,847	112,967,564	115,850,747
Additional Net DALYs averted†		2,930,606	1,812,819	4,695,964	1,812,681	4,695,864
Consumables budget required (%)	88.65%	93.55%	100%	100.00%	100.00%	100.00%
Medical officer capacity required (%)	63.67%	62.5%	78.40%	77.9%	78.32%	73.67%
Nursing staff capacity required (%)	33.79%	32.59%	43.69%	41.89%	43.29%	40.10%
Pharmaceutical staff capacity required (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Laboratory staff capacity required (%)	61.30%	61.04%	67.25%	72.05%	67.25%	71.48%
Mental health staff capacity required (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Nutrition staff capacity required (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Radiography staff capacity required (%)	0.43%	0.43%	0.43%	0.43%	0.43%	0.43%
VHT members required (%)	0.00%	6.59%	0.00%	6.81%	0.00%	6.84%
Medicine Retailers required (%)	0.00%	0.00%	4.99%	3.84%	4.36%	2.51%

† Compared to baseline.

baseline, using 10.4 per cent of their capacity – around 3.6 million more than with constraints. Integration of medicine retailers adds 18 interventions (total 56) and averts 16.7 million additional net DALYs at 12 per cent capacity – about 14.9 million more than under constraints. Joint integration expands the package by 20 interventions (total 58), yielding 17.2 million additional net DALYs averted while using 9.7 per cent of VHT and 8.6 per cent of medicine retailer capacity – 12.5 million more than with constraints. Although the package sizes for standalone medicine

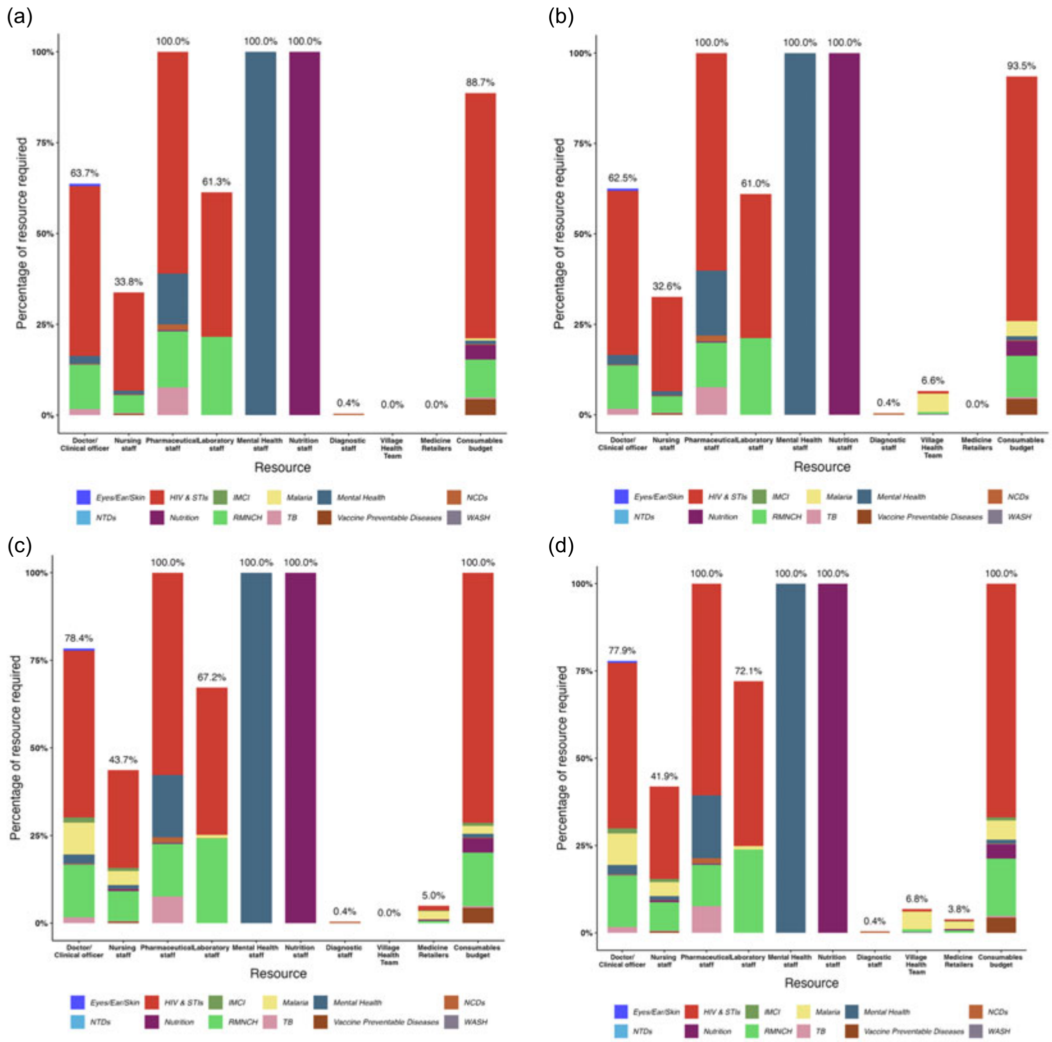

Figure 1. (a) Resource use by disease programme areas for the baseline strategy. (b) Resource use by disease programme areas for standalone VHT integration strategy. (c) Resource use by disease programme areas for standalone medicine retailer. (d) Resource use by disease programme areas for joint integration strategy integration strategy.

retailer and joint strategies are smaller than under case constraints, the overall net health gains are considerably higher. Online Appendix, Tables A15–17 list the interventions in the optimal package as well as the case distribution. The effect of markups becomes more evident when maximum case constraints are removed, leading to a reduction in package size, net DALYs averted, and share of medicine retailer used (online Appendix, Tables A18–19).

4.4. Value per provider and average productivity

The model estimated the maximum total cost (which can be incurred for the CBP to remain cost-effective at Uganda's current CET) to be $3,423 per VHT per year. Similarly, the estimated maximum total cost per medicine retailer was $19,792 per year (online Appendix, Table A20–21). The average cost-effectiveness of VHTs is around $41.64 per net DALY averted (or 0.024 net DALYs per dollar spent on the salary of the VHTs) (online Appendix, Table A22) under

Table 2. Interventions included in each strategy analysed

Programme	Intervention	Baseline	VHTs	Medicine retailers	Joint
Eyes/ear/skin	Uncorrected refraction error, annual screening for all primary and secondary school children (80%)	✓	✓	✓	✓
HIV & STIs	HIV testing services†	✓	✓	✓	✓
HIV & STIs	ART (first-line treatment) for men†	✓	✓	✓	✓
HIV & STIs	ART (first-line treatment) for women†	✓	✓	✓	✓
HIV & STIs	CRAG-LFA screening for cryptococcal meningitis among people living with HIV in Uganda	✓	✓	✓	✓
HIV & STIs	Female sex workers and clients	✓	✓	✓	✓
HIV & STIs	Interventions focused on male sex workers	✓	✓	✓	✓
HIV & STIs	Mass media communication to increase demand and improve use of condoms and condom provision	χ	χ	✓	✓
HIV & STIs	Paediatric ART	✓	✓	✓	✓
HIV & STIs	Peer education for sex workers	✓	✓	✓	✓
HIV & STIs	People Who Inject Drugs community outreach and peer education	χ	✓	χ	✓
HIV & STIs	Treatment of chlamydia	χ	✓	✓	✓
HIV & STIs	Treatment of gonorrhoea	✓	✓	✓	✓
HIV & STIs	Treatment of PID (Pelvic Inflammatory Disease)	✓	✓	✓	✓
HIV & STIs	Treatment of trichomoniasis	χ	χ	✓	✓
HIV & STIs	Voluntary medical male circumcision	✓	✓	✓	✓
HIV & STIs	Youth focused interventions	✓	✓	χ	χ
IMCI	Community-based management of Pneumonia	χ	χ	✓	✓
IMCI	Management of diarrhoea through Oral Rehydration Solution and Zinc	χ	χ	✓	✓
Malaria	Home management of fevers using antimalarial (artesunate-amodiaquine AAQ) – under 5	χ	✓	✓	✓
Malaria	Indoor residual spraying	✓	✓	✓	✓
Malaria	Insecticide treated materials	χ	✓	✓	✓
Malaria	Intermittent presumptive treatment of malaria	χ	χ	✓	✓
Malaria	ITN distribution to pregnant women	χ	χ	✓	✓
Malaria	Malaria: Management of suspected uncomplicated cases + Management of severe cases (50%)	χ	χ	✓	✓
Malaria	Uncomplicated malaria treatment (<5 years) – low to moderate transmission settings	χ	χ	✓	✓
Malaria	Uncomplicated malaria treatment (<5 years) – moderate to high transmission settings	χ	χ	✓	✓
Mental Health	Basic psychosocial support, advice and follow-up + anti-epileptic medication	✓	✓	✓	✓
Mental Health	Basic psychosocial treatment for anxiety disorders (mild cases)	✓	✓	✓	✓

(*Continued*)

Table 2. (*Continued*)

Programme	Intervention	Baseline	VHTs	Medicine retailers	Joint
Mental Health	Basic psychosocial treatment for mild depression	✓	✓	✓	✓
NCDs	Amputation	✓	✓	✓	✓
NCDs	Basic palliative care for cervical cancer	✓	✓	✓	✓
NCDs	Elective inguinal hernia repair	✓	✓	✓	✓
NCDs	Emergency inguinal hernia repair	✓	✓	✓	✓
NTDs	Trachoma Trichiasis cases surgery	✓	χ	✓	✓
Nutrition	Balanced energy-protein supplementation to pregnant women with insecure food availability	χ	✓	χ	✓
Nutrition	Deworming (Children)	χ	χ	✓	✓
Nutrition	Management of moderate acute malnutrition (children)	✓	✓	✓	✓
Nutrition	Vitamin A supplementation (0–4 years)	χ	χ	✓	✓
RMNCH	Antenatal corticosteroid for preterm labour	✓	✓	✓	✓
RMNCH	Case management of newborn complications at referral level	✓	✓	✓	✓
RMNCH	Caesarean section with indication	✓	✓	✓	✓
RMNCH	Caesarean Section with indication (with complication)	✓	✓	✓	✓
RMNCH	Clean practices and immediate essential newborn care (home)	✓	✓	✓	✓
RMNCH	Community-based newborn and child care	✓	✓	✓	✓
RMNCH	Comprehensive antenatal care	χ	χ	✓	✓
RMNCH	Condom promotion among key populations (MSM)	χ	χ	✓	✓
RMNCH	Daily iron and folic acid supplementation in pregnant women	χ	χ	✓	✓
RMNCH	Fistula	✓	✓	✓	✓
RMNCH	Home visits for clean postnatal practices	χ	χ	χ	✓
RMNCH	Hypertensive disease case management in pregnancy	χ	χ	✓	✓
RMNCH	Implant	χ	χ	✓	✓
RMNCH	Induction of labour (beyond 41 weeks)	✓	✓	✓	✓
RMNCH	Injectable	✓	✓	✓	✓
RMNCH	IUD	χ	χ	✓	✓
RMNCH	Kangaroo Mother Care (KMC)	✓	✓	✓	✓
RMNCH	Management of pre-eclampsia (mild and severe)	χ	χ	✓	✓
RMNCH	Pill	χ	✓	✓	✓
RMNCH	Promotion of breastfeeding	χ	χ	✓	✓
RMNCH	Syphilis detection and treatment in pregnancy	✓	✓	✓	✓
RMNCH	Visual inspection with acetic acid (VIA)	✓	✓	✓	✓

(*Continued*)

Table 2. (*Continued*)

Programme	Intervention	Baseline	VHTs	Medicine retailers	Joint
TB	Isoniazid Preventive Therapy for HIV + pregnant women	✓	✓	✓	✓
Vaccine Preventable Diseases	Malaria vaccination among children/infants	✓	✓	✓	✓
WASH	Hand washing with soap	✓	✓	✓	✓

ü Included; û Not Included.
See Online Appendix, Tables A9–12 for further details.

maximum case constraints. This is well below the 165$ per DALY averted CET for Uganda. Removing the maximum case constraint could nearly double the value for money for VHTs, improving the cost-effectiveness to $18.71 per net DALY averted (or 0.053 net DALYs per dollar) (online Appendix, A23)

5. Disussion and conclusion

This paper employs a constrained optimisation model to assess the added value of integrating CBPs – VHTs and medicine retailers – as new platform(s) for delivering UNEHCP. The findings demonstrate that their inclusion holds great potential for improving population health and system efficiency, expanding the optimal intervention package by 25 services and increasing net DALYs averted by approximately 4.7 million compared to a facility-only approach, even under constraints on what they can deliver and the proportion of patients they can treat. The overall increase in net DALYs averted is driven by shifting case management to VHTs and medicine retailers, which not only enables the inclusion of new interventions but also the expansion of coverage for existing interventions.

While integrating VHTs generates a greater population health impact, the size of the optimal package is larger for medicine retailers. This is because medicine retailers can directly substitute for facility pharmacists, one of the system's most binding constraints. VHTs, in contrast, engage in task-sharing that still requires facility staff, including pharmacists. Their relatively higher impact in the current model stems from their broader role in the interventions they support. VHTs' wider scope of practice and less binding case limits mean they can be deployed more extensively across higher-impact interventions within the optimal package. Medicine retailers, however, face tighter caps on the cases they can support for these interventions (see online Appendix, Table A1). Once these caps are reached, the model reallocates effort toward the remaining feasible interventions which have lower net benefits. Consequently, despite supporting a larger intervention package overall, medicine retailer integration yields lower health impact than VHT integration. The joint strategy leverages the complementary strengths of both provider types resulting in a larger optimal package and greater overall health gains than integrating either provider type alone.

Although both providers show considerable potential, our results reveal that they remain underutilised in our model – only about 6.8 per cent of VHT capacity and 3.8 per cent of medicine retailer capacity is employed. The limited use observed in the model can be explained by the interaction of three constraints: (1) the limited scope of interventions they are permitted to deliver, (2) constraints on the percentage of cases that they can support, and (3) reliance on constrained facility staff for service delivery. Addressing the current operational barriers faced by medicine retailers and VHTs such as supply chain stockouts, weak incentive structures, inadequate training, limited supervision, poor working conditions, and fragmented referral networks has the potential

Table 3. Summary of results from relaxing maximum case constraint for VHTs and medicine retailers

	Baseline (only facility-based workers)	Standalone integration of VHTs	Standalone integration of medicine retailers	Joint integration of VHTs and medicine retailers	Standalone integration of medicine retailers	Joint Integration of VHTs and medicine retailers
	Without markup				With markup	
Interventions in the optimal package	38	45	56	58	50	52
Net DALYs averted	111,154,883	117,678,106	127,885,655	128,353,046	126,565,976	127,116,423
Additional Net DALYs averted†		6,523,223	16,730,772	17,198,163	15,411,093	15,961,540
Consumables budget required (%)	88.65%	100.00%	100.00%	100.00%	100.00%	100.00%
Medical officer capacity required (%)	63.67%	70.60%	100.00%	100.00%	82.01%	82.98%
Nursing staff capacity required (%)	33.79%	35.91%	54.47%	53.60%	45.95%	43.77%
Pharmaceutical staff capacity required (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Laboratory staff capacity required (%)	61.29%	73.41%	90.27%	89.78%	77.31%	77.66%
Mental health staff capacity required (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Nutrition staff capacity required (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Radiography staff capacity required (%)	0.43%	0.43%	0.43%	0.43%	0.43%	0.43%
VHT members required (%)	0.00%	10.36%	0.00%	9.73%	0.00%	3.96%
Medicine Retailers required (%)	0.00%	0.00%	11.90%	8.62%	8.50%	5.66%

† Compared to baseline.

to unlock greater health gains and should be prioritised in policy dialogue. Further, expanding the role and remit of CBPs through structural and regulatory reform should also be explored to improve future system efficiency and impact. For medicine retailers, whose modelled role was limited to drug dispensing over safety concerns, this could mean leveraging their common role as first points of care in Uganda (Kitutu *et al.*, 2017a) to support task-sharing in community case management (Kitutu *et al.*, 2017b), provided adequate capacity-building, regulation, and monitoring (eg, peer supervision models (Bagonza *et al.*, 2021)) are in place. Similarly, there is value in exploring alternative ways VHTs can support service delivery beyond task-sharing (eg, combined with task-shifting Yankam *et al.*, 2023). Expanding roles would, however, require substantive investment, and their practical feasibility needs careful assessment. Future research should evaluate the opportunity costs, safety implications, quality of care, and political acceptability of expanded provider roles before such approaches are adopted at scale. It is also important to acknowledge that our model may underestimate the true contributions of CBPs, since it is based on what is officially prescribed as per guidelines. In practice, CBPs are often overextended – taking on tasks beyond their formal remit and making informal yet critical contributions that frequently go unrecognised.

Incentivising medicine retailers through markups offer considerable benefits, but this strategy also limits their involvement and the net health gains they can deliver. The model currently applies a uniform 25 per cent markup across interventions, but exploring intervention-specific markups could yield further insights into pricing impacts. The 25 per cent markup considered aligns with the typical wholesale and distribution markups (25–50 per cent), representing a more realistic reimbursement scenario than the much higher retail markups seen in Uganda (50–600 per cent) (O'Hanlon *et al.*, 2016). The absence of pricing policies or regulatory mechanisms in Uganda makes it difficult to control private sector markups, highlighting an urgent need for dialogue on price regulation (Ministry of Health, 2015). To ensure medicine retailers contribute more cost-effectively, government could consider capping markups, setting fixed percentages, or subsidising the upstream supply chain (Mayora, 2021). These measures would require strong regulatory systems and careful evaluation of potential unintended effects on consumers and the broader health system. As such, any reform must be preceded by rigorous planning and evidence-based assessment.

We also present the maximum total cost per provider, averaged across the full pool of VHTs and medicine retailers. This provides a benchmark for the level of investment that remains cost-effective given current workforce size. It can help identify areas of underinvestment, inform resource allocation, address systemic barriers to effective deployment, and highlight opportunities to better leverage the existing community-based workforce. VHTs offer excellent value for money, with a cost of just \$42 to avert one net DALY – equivalent to an average productivity of 0.024 net DALYs per dollar. While this is lower than the productivity of facility-based cadres (see online Appendix, Table A22), the difference may partly be due to conservative assumptions made about the scope of their work and their considerable underutilisation. Nevertheless, they remain cost-effective and demonstrate considerable untapped potential. Expanding the scope of VHTs appears to be a highly promising strategy for efficient health service delivery as supported by evidence which shows that removing caseload constraints improves their cost-effectiveness to \$19 per DALY averted.

Like any approach, this is not without limitations. First, the model's results rely heavily on the availability and quality of underlying evidence as well as detailed information on the resource needs of each intervention. Despite expanding to 194 interventions from 125 in Mohan et al. (2023), some potentially cost-effective interventions remain excluded due to limited evidence. For those included, we have updated our previous database with the most recent and reliable estimates available. However, even with global repositories like WHO-CHOICE, reporting of cost-effectiveness evidence is often not standardised. As a result of this we had to rely upon numerous sources to obtain the required data which not only led to varying quality but also inconsistencies in terms of discount rates, time horizons, and lack of context-specific estimates. Second, we rely upon external evidence for the opportunity cost of the health budget in Uganda in the long term (CET) and are unable to directly use our framework to determine this value, because not all constraints could be explicitly included in our linear programme. Moreover, the CET we used assumes a perfectly fungible budget but in reality, health funding is often siloed, especially with donor support earmarked for specific programmes. This implies that the opportunity costs of health funding is not uniform across earmarked budgets and different CETs may be appropriate for different programmes (Revill *et al*., 2020). Third, interventions are treated as independent – meaning their costs and effects do not depend on whether other interventions are included – and both costs and health benefits scale linearly with coverage. In reality, there are likely to be complementarities and interactions between interventions as well as nonlinearity in production functions. The framework can, however, accommodate combinations of interventions and nonlinearity by adjusting parameters at different coverage thresholds as better data becomes available.

Fourth, the model does not fully capture the implications of reallocating tasks away from scarcer, highly trained providers to less trained providers. For example, shifting certain responsibilities from doctors to VHTs may reduce costs but could also impact effectiveness of care. Conversely, redistributing workload might improve quality of care by alleviating pressure on formal healthcare workers and easing supply-side constraints. The analysis would be strengthened by more precise cost-effectiveness data that reflects differences in treatment outcomes – such as early diagnosis, prevention, quality, and adherence – across provider types. Fifth, our model assumes perfect divisibility of resources (across health facilities) and costless transition when integrating these additional providers in health service delivery. In practice, governments must account for real-world implementation costs, including training, supervision, remuneration, recruitment, procurement, and strategic deployment of health workers. Sixth, we assume that patient-facing time per case is the same for medicine retailers and facility-based pharmacists, although this may not hold in practice; future work should revisit this assumption as relevant data becomes available. Lastly, we exclude the for-profit private sector from our workforce constraints.

Despite these limitations, we believe our analysis offers a systematic approach to generate evidence on the value that can be generated by new platforms and contributes to informing future policy considerations around such strategic decisions. It underscores the importance of integrating both government-supported CHWs and private micro-enterprises, like drug shops and retail pharmacies, into the wider health system. The model can also help identify which service packages are best suited for delivery by these CBPs, enabling a shift away from fragmented, vertical programmes. The inherent flexibility of the model allows it to be adapted to various settings and to evaluate different CBP roles. Further, other objectives such as equity and financial risk protection (Lofgren *et al*., 2021) may also be relevant objectives and could be used in conjunction with the efficiency-focused objective of health maximisation applied here. Strategically investing in and deploying these providers is crucial for achieving equitable access to essential health services and advancing progress toward UHC. Future research will explore how integrating these cadres may help address demand-side constraints on healthcare utilisation – an area not currently accounted for in this model.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1744133126100644.

Data availability statement. All input data, sources, and full set of results are available in the online supplementary material. The R script for the analysis is freely available on GitHub.

Acknowledgements. Google Gemini (publicly available web interface https://gemini.google.com, accessed March–May 2025) was used for debugging and syntax support during code development. It was not used in study design, analysis, or interpretation of results, and no proprietary data were entered. All code development, analysis, interpretation of results, and manuscript preparation were carried out by the authors.

Financial support. This work was supported by funding received from the Global Institute for Disease Elimination (GLIDE) as part of the Thanzi Labwino (Better Health) research project.

Competing interests. The authors have no relevant financial or non-financial interests to disclose.

Ethical statement. The study relies upon secondary data, consisting exclusively of national level aggregate figures and does not use any personally identifiable information. No primary data collection was undertaken, and all data were obtained with the necessary permissions.

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Cite this article: Rao M, Mohan S, Mayora C, Ekirapa E, McGuire F, Nakimuli B, Namirembe B, Ochanda P, Ssempala R, Ssennyonjo A, Revill P, Walker SM and Ssengooba F (2026). Redesigning national health service delivery: the case for community-based health service providers in Uganda. *Health Economics, Policy and Law* 1–20. https://doi.org/10.1017/S1744133126100644