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Modelling costs of community-based HIV self-testing programmes in Southern Africa at scale: an econometric cost function analysis across five countries

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ABSTRACT

Background Following success demonstrated with the HIV Self-Testing AfRica Initiative, HIV self-testing (HIVST) is being added to national HIV testing strategies in Southern Africa. An analysis of the costs of scaling up HIVST is needed to inform national plans, but there is a dearth of evidence on methods for forecasting costs at scale from pilot projects. Econometric cost functions (ECFs) apply statistical inference to predict costs; however, we often do not have the luxury of collecting large amounts of location-specific data. We fit an ECF to identify key drivers of costs, then use a simpler model to guide cost projections at scale.

Methods We estimated the full economic costs of community-based HIVST distribution in 92 locales across Malawi, Zambia, Zimbabwe, South Africa and Lesotho between June 2016 and June 2019. We fitted a cost function with determinants related to scale, locales organisational and environmental characteristics, target populations, and per capita Growth Domestic Product (GDP). We used models differing in data intensity to predict costs at scale. We compared predicted estimates with scale-up costs in Lesotho observed over a 2-year period.

Results The scale of distribution, type of community-based intervention, percentage of kits distributed to men, distance from implementer's warehouse and per capita GDP predicted average costs per HIVST kit distributed. Our model simplification approach showed that a parsimonious model could predict costs without losing accuracy. Overall, ECF showed a good predictive capacity, that is, forecast costs were close to observed costs. However, at larger scale, variations of programme efficiency over time (number of kits distributed per agent monthly) could potentially influence cost predictions.

Discussion Our empirical cost function can inform community-based HIVST scale-up in Southern African countries. Our findings suggest that a parsimonious ECF can be used to forecast costs at scale in the context of financial planning and budgeting.

Key questions

What is already known?

- Following success demonstrated with the HIV Self-Testing AfRica) Initiative, HIV self-testing is being added to national HIV testing strategies in Southern Africa.
- Community-based models delivering HIV self-testing either at people's homes or within the community setting with mobile outreach are a convenient approach for reaching undertested groups such as young people (16–25 years old) and men.
- There is little guidance or empirical evidence on methods for forecasting costs at scale for programming and planning.

What are the new findings?

- Our study developed an econometric cost function for scaling up community-based HIV self-testing programmes for the general population in Southern Africa, using data from five countries.
- Our model simplification approach showed that we could use a more parsimonious model, including scale, type of community-based intervention, percentage of men reached by the programme, distance from implementer's warehouse and per capita Growth Domestic Product, to predict costs without significantly losing accuracy.

What do the new findings imply?

- The extrapolation of cost predictions to inform community-based HIV self-testing scale-up in Southern African countries is possible with our empirical cost function.
- Our analysis adds to the literature on the trade-off between simplicity versus accuracy in cost projection methods.

INTRODUCTION

The HIV burden remains concentrated in Southern Africa, with estimated adult prevalence ranging between 10.6% in Malawi and

25.6% in Lesotho in 2018.[1] Expanding access to HIV testing services (HTS) and ensuring linkage to prevention or timely antiretroviral therapy initiation for people living with HIV is vital to achieving epidemic control. HIV self-testing (HIVST) is an additional testing modality where an individual collects his or her own oral fluid or blood sample, conducts the test and interprets results. HIVST has increased the uptake and frequency of testing among individuals who would not test otherwise.[2 3] The Unitaid-funded Self-Testing AfRica (STAR) Initiative led by Population Services International (PSI) started implementing HIVST delivery models in southern Africa in 2016.[4] Many HIVST distribution models were evaluated, including community-based, workplace, public and private sector facility-based primary distribution strategies, and secondary distribution strategies to sexual partners and peers among key populations.[5]

Community-based models delivering HIVST either at people's homes or within the community setting with mobile outreach were shown to be a convenient approach for reaching undertested groups such as young people (16–25 years old) and men.[6–10] Although community-based approaches are expensive from a provider perspective, they decrease users' costs in accessing HIV testing, in particular among working men whose time might be more expensive.[9 11 12] Following the success demonstrated in the STAR Initiative, the Lesotho Ministry of Health added HIVST to its revised national HTS strategic plan for 2018–2023.[13] An analysis of the costs of scaling-up HIVST (increasing the provision of HIVST kits) was needed by country planners to inform the HIVST national scale-up plans and budget in Lesotho. However, there is little guidance or empirical evidence on methods for projecting costs at scale for programming and planning.[14 15]

Cost functions can be derived from a production function to estimate the total cost of production given a specific output produced. The simplest cost function multiplies a single unit cost by a quantity—the commonly used 'simple cost multiplier' (SCM). It is a practical costing method used for high level budgeting.[15] Accounting cost functions (ACFs) identify all the cost inputs to a production process (equipment, personnel, etc) over a defined costing period (usually 1 year) and categorise them as fixed, semi-fixed or variable costs in the short run or all variable in the long run.[14–17] Econometric cost functions (ECF) do not follow the production process but rather apply statistical inference to predict costs. The challenge of ECF is to reflect the complexity of real-world production process with a mathematical model of inputs and outputs.[14 16] In most studies, we do not have the luxury of collecting large amounts of location-specific cost data, and applications of ECF for cost predictions are rare.[14 18] In the absence of detailed data, SCM is commonly used.

This study aims to fit an ECF to estimate the cost drivers of the community-based HIVST programmes in Southern Africa using data from Malawi, Zambia, Zimbabwe and South Africa. We then inform the use of ECF to predict costs at scale by comparing ECF models with different level of data requirements. Finally, we assess the validity of our empirical ECF by comparing projected costs with observed costs at scale in Lesotho. We select Lesotho as our case study because we conducted in this country a longitudinal microcosting analysis of HIVST scale-up from a real-world intervention over 2 years of implementation.[19]

METHODS

Setting: data sources

We estimated the full economic costs of community-based HIVST distribution in 92 sites across Malawi, Zambia, Zimbabwe, South Africa and Lesotho (table 1).[12 19 20] We collaboratively developed cost analysis methods following standard guidelines and analysed data, ensuring consistency of methods across countries.[15 21] Programme expenditures supplemented by on-site observation and monitoring and evaluation data were used to estimate HIVST distribution costs.[22] Costing studies in Malawi, Zambia and Zimbabwe were conducted as part of larger randomised controlled trials.[12] We also conducted time and motion studies. Cost data collection and analysis methods are described in detail elsewhere.[12 23 24] Some variations of the 'community-based' intervention were observed between countries and are described in online supplemental appendix text S1. For resources shared across different services, models or levels, we allocated expenditure using allocation factors summarised in online supplemental appendix table S1. Costs were adjusted for inflation using each country's Consumer Price Index and presented in 2019 US$.[15 25]

For cost determinants (or cost drivers) presented in table 2, data on scale, number of HIVST distributors per site, efficiency, type of community-based intervention, percentages of HIVST kits distributed to men and to those who never tested for HIV were collected through the PSI monitoring and evaluation programme. Distance between distribution site and PSI headquarters, size of catchment population, HTS costs and positivity rates at nearby health facilities, per capita Growth Domestic Product (GDP) in 2019 US$, were collected as part of the STAR costing studies.[12 24]

Study timelines

Cost data were collected between June 2016 and June 2019 across all countries (figure 1). For the analysis of observed costs at scale in Lesotho, costs were collected between August 2017 and April 2019 (17 months) in five districts (Berea, Leribe, Mafeteng, Maseru and Mohale's Hoek) where HIVST kits were distributed. We observed three scale-up phases of approximately 6 months each in Lesotho (period 1: December 2017–April 2018; period 2: May 2018–October 2018; and period 3: November 2018–April 2019).

Table 1 Overview of interventions by countries

	Malawi	Zambia	Zimbabwe	South Africa	Lesotho	Source
Per capita Gross Domestic Product (2019 US$)	$412	$1305	$1464	$6001	$1118	52
National HIV prevalence among adults 15–59 years (%) – 2018	10.6	12.0	14.6	20.4	25.6	53–57
Intervention district	Blantyre, Machinga, Mwanza and Neno	Choma, Lusaka, Ndola and Kapiri	Mberengwa, Buhera Masvingo, Chivi, Gweru, Bulilima, Gutu and Mazowe	City of Tshwane, City of Johannesburg	Maseru, Berea, Leribe Mohale and Mafeteng	58
Definition of site	Catchment area of a rural public primary health clinic	Catchment area of a rural public primary health clinic	Ward (subdivision of a district)	District	Catchment area of a PSI fixed site (~1 per district), that is, a district and across all five districts, for each period 1–3	12
Number of sites	11	16	44	3	18	58
Location: rural; urban or periurban	11; 0	8; 8	44; 0	0; 3	4; 1	58
Analysis period	June 2016–May 2017 (12 months)	June 2016–May 2017 (12 months)	June 2016–May 2017 (12 months)	June 2018–June 2019 (13 months)	August 2017–April 2019 (17 months)	58
Total number of HIVST kits distributed in included sites during observation period	152 671	103 589	92 559	154 111	51 676	12 19 58

HIVST, HIV self-testing; PSI, Population Services International.

Econometric analysis

Econometric model specification using data from Malawi, Zambia, Zimbabwe and South Africa

We start our analysis with the conventional cost function where total costs are a function of quantity and prices.[17] We use a linear regression approach (Ordinary Least Squares) and use average cost per HIVST kit distributed (arithmetic mean) as the dependent variable.[26] We use average costs instead of total costs as our sample is composed of sites at various administrative levels between countries (district and catchment area of health facility), thus making comparison more intuitive and because the unit of output (HIVST kits distributed) is clearly defined (Equation 1). We included PSI central costs (country and regional offices) in the average cost estimates to allow for comparison with observed costs at scale. Because the cost data were highly skewed to the right with a heavy tail, we log-transformed the dependent variable.[26]

Cost determinants were selected based on the economic theory of production function, through programme observation, and the literature on cost functions for HIV care services.[14 16 27–39] Cost drivers' description, expected effect on costs and justification for inclusion in the model are presented in table 2, following Lépine and colleagues'[35] approach for the categorisation of determinants. We used multiple imputation for missing data; although overall missingness was low, mean and standard deviation (SD) were comparable before/after imputation. We checked model robustness with the addition/removal of single regressors. The cost function was fitted using the R package.[40]

Equation 1

$$C = \sum_k AC_k \cdot Q_k \text{ with } Log\left(AC_k\right) = \beta_0 + \beta_1 * Scale_k + \beta_2 * Scale_k^2 + \beta_3 * Scale_k^3 + \beta_4 * Distributor\_site_k + \beta_5 * Campaign_k + \beta_6 * Log\left(Efficiency_k\right) + \beta_7 * Perc\_men_k + \beta_8 * Perc\_never\_tested_k + \beta_9 * Distance_k + \beta_{10} * Population_k + \beta_{11} * Positivity_k + \beta_{12} * Cost\_facility_k + \beta_{13} * Price\_level_k$$

Where:

C: total programme cost k: level of analysis: district, catchment area of health facility.

$Log(AC_k)$: natural logarithm of the average cost per scale variable Q_k for level k.

Scale: average number of HIVST kits distributed per month.

Distributor_site: average number of distributors per site.

Campaign: type of intervention (campaign style vs fixed distributors).

Log(Efficiency): natural logarithm of the number of HIVST kits distributed per agent monthly.

Perc_men: percentage of HIVST kits distributed to men out of total distribution volumes.

Table 2 Variable categories, description, expected effect on costs and justification

Variable category	Variable name	Description	Expected effect on costs	Justification	Source
Dependent variable	Average costs per HIVST kit distributed including central costs	Unit costs per HIVST kit distributed including in-country central costs and start-up costs in 2019 US$	NA	NA	12
Quantities	Scale	Number of HIVST kit distributed by site during the observation period	±	(Dis)Economies of scale	PSI
Site organisational characteristics	HIVST distributors	Number of full time equivalent HIVST distributor in each site	±	Increase your coverage and # of HIVST kits distributed (so lower average costs per kit distributed), but also increase personnel costs	PSI
	Campaign style	Variable coded 1 if the same distributors travel from sites to sites (campaign style distribution) or 0 if they live within the community	+	In some countries, HIVST kits distribution was more conservative and restricted by campaign duration in each site, so this approach could drive costs higher due to lower volumes of kits distributed and travel costs	PSI
	Efficiency	Number of HIVST kits distributed per agent per month	–	The higher the number of HIVST kits distributed per agent, the more efficient they are and the lower is the cost per kit distributed	PSI
Characteristics of population targeted	% HIVST kits distributed to men	Number of kits distributed to men – also measure if programme is targeting well (proxy for quality)	+	Men might be harder to reach and to convince to take a kit, might lead to higher costs of provision	PSI
	% never tested for HIV	% of people who never tested for HIV	–	Higher knowledge of HIV status might lead to lower demand for testing, including HIVST, leading to increased average cost per kit distributed	STAR household surveys
Environmental characteristics	Distance	Distance from central warehouse to site in kilometres	+	Longer distance from the PSI headquarters and warehouse might lead to high costs of service provision	PSI, Google Maps
	Catchment population	Size of the catchment population of the site regardless of eligibility	–	Number of potential HIVST recipients affect levels of distribution potentially leading to economies of scale	PSI, Ministry of Health
	Positivity at health facility	Annual new HIV positive identified over total tested at nearby health facility (positivity rate)	+	If the health facilities experience high positivity rates, the demand for HIVST might be lower leading to increased average costs (higher costs to reach the last % of target population)	PSI, Ministry of Health
	HTS average cost at health facility	Average cost per person tested with HTS at the nearest health facility	+	Although not a determinant, a significant correlation might suggest the effect of other unobserved environmental characteristics on costs	12 24
Input price level	Price level	Per capita Growth Domestic Product in 2019 US$	+	Proxy for input price level variation across countries	52

HTS, HIV testing services; PSI, Population Services International; STAR, Self-Testing AfRica.

Perc_never_tested: percentage of HIVST kits distributed to people who never tested before out of total distribution volumes.

Distance: distance of site from implementer's central warehouse (in kilometres).

Population: size of total population at the site.

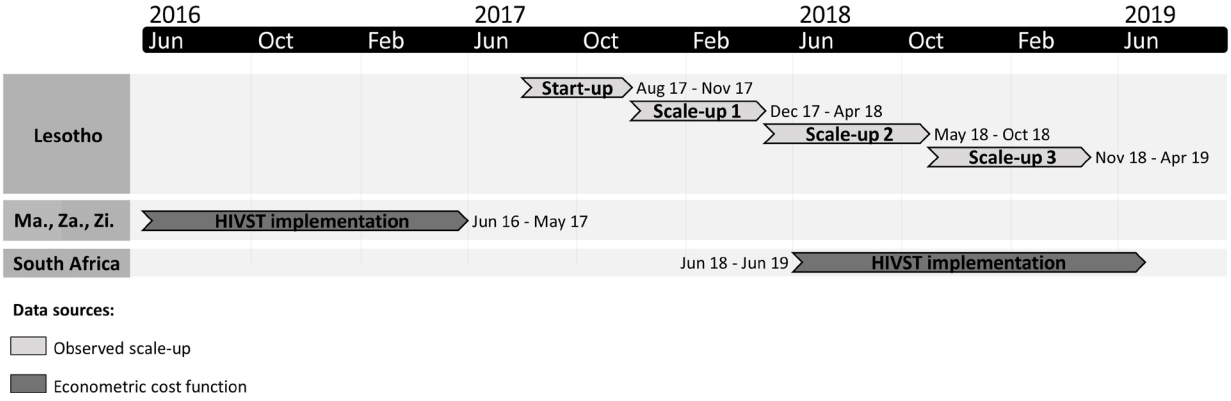

Figure 1 STAR costing period and data sources by country for each cost analysis. HIVST, HIV self-testing; MA, Malawi; STAR, HIVSelf-Testing AfRica; Za, Zambia; Zi, Zimbabwe.

Positivity: positivity of rapid HIV testing (number of HIV-positive case found out of total number of persons tested) at nearby health facilities.

Cost_facility: average cost per facility-based HIV testing session at nearby health facilities.

Price_level: proxy for input price level variation across countries based on per capita GDP.

β_0: model intercept.

β_1-β_{13}: model coefficients computed using empirical dataset.

Q_k: quantity of units for level k: number of HIVST kits distributed.

Using the model to predict costs at scale in Lesotho

Coefficients in a log-linear model are the estimated percentage change—elasticity—in the dependent variable for a unit change in the independent variable.[41 42] We used the 'predict' function in R package to estimate average cost for various scale values. We used exponential function to back transform estimated average costs as our error terms were normally distributed.[43] We compared total costs at 'national' (all five districts) and district level to allow for comparison between observed costs (scale-up periods 1, 2 and 3) and predicted costs. The likelihood ratio test (LRT), comparing the goodness of fit of two statistical models, was used to assess whether we could simplify the model (ie, reduce the number of parameters in our regression model) for cost projections.

Patient and public involvement

To conduct our costing study from a provider perspective, it was not appropriate to involve patients or the public in the design, or conduct, or reporting, or dissemination plans of our research.

Ethical approvals

The trials are registered under the Clinical Trials Network (ClinicalTrials. gov) under registration numbers NCT02793804, NCT02718274 and Pan African clinical trials registry PACTR201607001701788 for Malawi, Zambia and Zimbabwe. Informed consent was obtained from all individual participants included in the time and motion study.

RESULTS

Descriptive statistics

Descriptive statistics (mean, SD, min and max) of data are presented for the full sample and for each country in table 3. Sample mean of average cost per kit distributed was $14.58 (median: $13.54). On average, each site had 26 (range: 2–272) distributors and distributed 993 (range: 160–5904) kits. Part of the strategy was to reach men, and those who had never tested before, these groups made up, on average, 48% and 12%, respectively, of kit recipients. Average distance of site to warehouse was 162 km, population size of 672 429 inhabitants and, finally, positivity rate of 8% and the cost of provider-delivered HIV testing was $6.22 per person tested at nearby health facilities.

Determinants of HIVST average costs at programme level and model simplification

We retained a combination of three *scale* variables, normally distributed, quadratic and cubic, because they explained the largest share of the variance (R^2 was the highest).[44 45] We explored several functional forms for other cost determinants; only *efficiency* was log-transformed as it improved model fit. Other determinants were kept with a normal distribution. The correlation matrix showed high correlation between *population* and *scale*, between *distributors* and *campaign style*, and low or no correlation otherwise (online supplemental appendix figure S1); therefore, the variables *population* and *distributors* were excluded. Multicollinearity was assessed on the remaining cost drivers using the variance inflation factor (VIF) test and was acceptable (mean VIF: 2.94). We tested for heteroscedasticity using the Breusch-Pagan test and failed to reject the null hypothesis (p>0.05); therefore, heteroscedasticity was not present in the model.

We progressively added cost determinants to our model starting with *scale*, followed by organisational characteristics, characteristics of the population reached, environmental factors and *price level* (table 4). Major cost determinants were *scale*, *campaign-style* distribution, *% of kits distributed to men*, *distance* from the implementer's warehouse and *price level* (*model 5*). We found

Table 3 Descriptive statistics

	Total sample				Malawi				Zambia			
Number of sites (N)	92				11				16			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Average cost per HIVST kit distributed (including central costs)	14.58	2.8	7.2	54.44	10.65	2.93	7.20	17.04	21.11	10.73	7.91	50.01
Average cost per HIVST kit distributed (excluding central costs)	10.73	1.7	4.52	41.49	5.56	1.03	4.52	7.52	12.39	5.36	6.40	26.50
Scale	1319	819	160	5904	1045	1005	380	3511	589	398	160	1859
HIVST distributors	26	26	2	40	13	8	6	31	9	3	5	18
Campaign style	0.56	0.5	0	1	0	0	0	0	0	0	0	0
Efficiency	109	56	13	486	75	22	48	113	64	23	27	103
% HIVST kits distributed to men	48	8	31	76	50	3	45	55	56	25	33	76
% HIVST kits distributed to people who never tested for HIV	12	2	0	22	18	3	11	22	18	3	13	21
Distance	162	35	3	647	85	55	20	180	210	122	11	348
Catchment population	672 429	824 163	549	4 949 347	24 007	21 804	4452	82 581	48 379	50 924	10 096	172 753
Positivity	0.08	0.03	0	0.62	0.09	0.04	0.03	0.14	0.09	0.07	0.00	0.27
HTS average cost	6.22	2.5	2.3	34.78	3.97	1.09	2.64	5.81	4.45	1.41	2.49	7.17

	Zimbabwe				South Africa				Lesotho			
Number of sites (N)	44				3				18			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Average cost per HIVST kit distributed (including central costs)	15.79	7.32	10.19	54.44	13.54	5.36	9.69	19.67	11.79	3.79	6.97	22.81
Average cost per HIVST kit distributed (excluding central costs)	11.65	5.66	7.44	41.49	12.59	5.38	8.76	18.74	11.45	3.64	6.80	21.96
Scale	1052	401	160	2101	2901	2636	971	5904	1009	1007	188	4184
HIVST distributors	23	7	5	40	10	7	2	14	75	71	10	272
Campaign style	1	0	1	1	0	0	0	0	0	0	0	0
Efficiency	47	14	13	80	346	155	130	486	15	7	5	40
% HIVST kits distributed to men	44	4	38	55	51	12	37	60	38	9	31	56
% HIVST kits distributed to people who never tested for HIV	12	4	5	21	11	8	3	18	2	1	0	2

Continued

Table 3 Continued

	Zimbabwe				South Africa				Lesotho			
Number of sites (N)	44				3				18			
Variables	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Distance	349	141	33	647	90	85	17	184	76	54	3	130
Catchment population	8023	24 453	549	165 590	2 989 107	2 117 801	742 822	4 949 347	292 627	144 458	165 590	519 186
Positivity	0.07	0.10	0.00	0.62	0.13	0.05	0.10	0.18	0.03	0.01	0.03	0.04
HTS average cost	7.15	5.74	2.30	34.78	11.21	6.94	5.02	18.71	4.30	1.32	2.49	6.15

HIVST, HIV self-testing; SD, Standard deviation.

a negative association between *scale* and average cost. If *scale* increases by 100 HIVST kits distributed, average cost decreases by 0.16%. *Campaign-style* distribution increased costs by 19%. An increase in 1% of kits distributed to men increased average cost by 0.67%. An increase of the *distance* between the implementer's warehouse and HIVST distribution areas by 1 km increased costs by 0.01%. Finally, an increase of per capita GDP (*price_level*) by $10 led to an increase of average cost by 0.01%.

For the model simplification analysis, we removed *% never tested*, *positivity* and *HTS costs at health facility* in *model 6*, as these determinants were not significant (table 5). *Model 5* did not significantly improve fit to the data than *Model 6* (LRT: p value: 0.82). Additionally, *model 7*, where *efficiency* was removed, did not significantly reduced goodness of fit than *model 6* (LRT: p value: 0.67).

Observed costs at scale in Lesotho

The cost analysis (online supplemental appendix table S2) was conducted for each of the three costing periods at national and district levels. The main cost drivers identified were personnel costs at national level (9%, 12% and 9% for periods 1, 2 and 3 respectively), district level (29%, 29% and 31%) and community outreach (27%, 28% and 21%), as well as HIVST kits costs (25%, 20% and 30%). Overall, HIVST distribution volumes were decreasing between periods 1 and 2 (14 099 and 12 471 kits), then increasing between periods 2 and 3 (12 471 and 25 106 kits). Between districts, we observed wide variation in HIVST kit distribution volumes ranging from 1130 kits (Mohale's Hoek, period 2) to 7958 kits (Leribe, period 3). At national level, average cost per kit distributed varied between periods: $10.69, $13.71 and $9.12 in periods 1, 2 and 3, respectively. At district level, wide variation was observed with average cost ranging from $6.97 (Leribe, period 3) to $22.81 (Berea, period 2).

Predicting costs at scale in Lesotho using the ECF with varying levels of complexity and comparison with observed costs at scale

We present observed total costs for each scale-up period at national and district level in Lesotho, against projected costs from *models 5–7* (figure 2). Overall cost projections at given scale were close to observed costs at district level and at national level in period 1, whereas we report some discrepancies at national level in periods 2 and 3. The comparison of projected total costs also showed that more parsimonious ECF (*model 7*) were not less accurate than more data hungry ECF (*model 5*). Simplified models were more precise due to narrower 95% CIs but would sometimes not include the observed costs in their range (*model 5* vs *model 7*: all districts – period 2).

DISCUSSION

Our study developed an econometric cost function for scaling up community-based HIVST programmes for the general population in Southern Africa, using data from five countries. Our results suggest that programme

Table 4 Determinants of HIVST average costs at programme level

	Model 1		Model 2		Model 3		Model 4		Model 5	
Parameters	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Constant	3.501***	0.125	3.428***	0.335	3.135***	0.390	2.395***	0.405	3.153***	0.437
Scale (in thousands)	−1.261***	0.250	−1.935***	0.316	−1.889***	0.319	−1.529***	0.314	−1.578***	0.291
Scale∧2 (in millions)	0.388***	0.132	0.684***	0.149	0.656***	0.150	0.492***	0.146	0.553***	0.137
Scale∧3 (in billions)	−0.036**	0.016	−0.068***	0.018	−0.064***	0.018	−0.046***	0.017	−0.056***	0.016
Campaign-style			0.364***	0.101	0.392***	0.104	0.169	0.108	0.174*	0.100
Efficiency			0.050	0.095	0.071	0.093	0.171*	0.095	−0.049	0.109
% HIVST kits distributed to men					0.533**	0.246	0.737***	0.228	0.511**	0.221
% HIVST kits distributed to people who never tested for HIV					−0.557	0.769	−1.236*	0.722	−0.097	0.748
Distance (in thousands)							1.062***	0.279	0.603**	0.292
Positivity							0.071	0.352	0.177	0.327
HTS average cost							−0.001	0.006	−0.004	0.006
Price_level (in thousands)									0.139***	0.041
No. of observations	74		74		74		74		74	
R^2	0.51		0.63		0.66		0.74		0.78	
R^2 adjusted	0.49		0.60		0.62		0.69		0.74	

***P<0.01, **p<0.05, *p<0.10.
HIVST, HIV self-testing; SE, Standard error.

Table 5 Model simplification approach

	Model 5		Model 6		Model 7	
Parameters	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Constant	3.153***	0.437	3.110***	0.418	2.963***	0.191
Scale (in thousands)	−1.578***	0.291	−1.630***	0.271	−1.662***	0.257
Scale^2 (in millions)	0.553***	0.137	0.575***	0.129	0.585***	0.126
Scale^3 (in billions)	−0.056***	0.016	−0.059***	0.015	−0.060***	0.015
Campaign style	0.174*	0.100	0.187**	0.093	0.205**	0.080
Efficiency	−0.049	0.109	−0.037	0.092		
% HIVST kits distributed to men	0.511**	0.221	0.519**	0.216	0.542**	0.208
% HIVST kits distributed to people who never tested for HIV	−0.097	0.748				
Distance (in thousands)	0.603**	0.292	0.582**	0.245	0.623***	0.222
Positivity	0.177	0.327				
HTS average cost	−0.004	0.006				
Price_level (in thousands)	0.139***	0.041	0.133***	0.035	0.126***	0.029
No. of obs.	74		74		74	
R^2	0.78		0.77		0.77	
R^2 adjusted	0.74		0.75		0.75	
Likelihood ratio test: model 5 versus model 6, and model 6 versus model 7						
Difference of χ^2 values (df)			0.93 (3)		0.18 (1)	
P value			0.82		0.67	

***P<0.01, **p<0.05, *p<0.10; df calculations: model 5 versus model 6: 13–10=3, model 6 versus model 7: 10–9=1.
HIVST, HIV self-testing; SE, Standard error.

design characteristics, including the scale of HIVST distribution, type of community-based intervention, characteristics of the population targeted with HIVST (men), distance from implementer's headquarter and per capita GDP can be used to predict average costs. These findings are consistent with previous studies on HIV prevention cost functions highlighting the role of scale as the major cost determinant among other cost drivers.[35 36 39 46] We also found that reaching men was associated with higher average HIVST distribution costs. Previous studies have shown that men's uptake of community HIV testing is often lower than uptake in women, as men are less likely to be present when mobile testing teams visit households, or might be more reluctant to take a kit, therefore increasing provision costs.[5 47 48] In addition, it is increasingly relevant to account for decreasing returns to scale

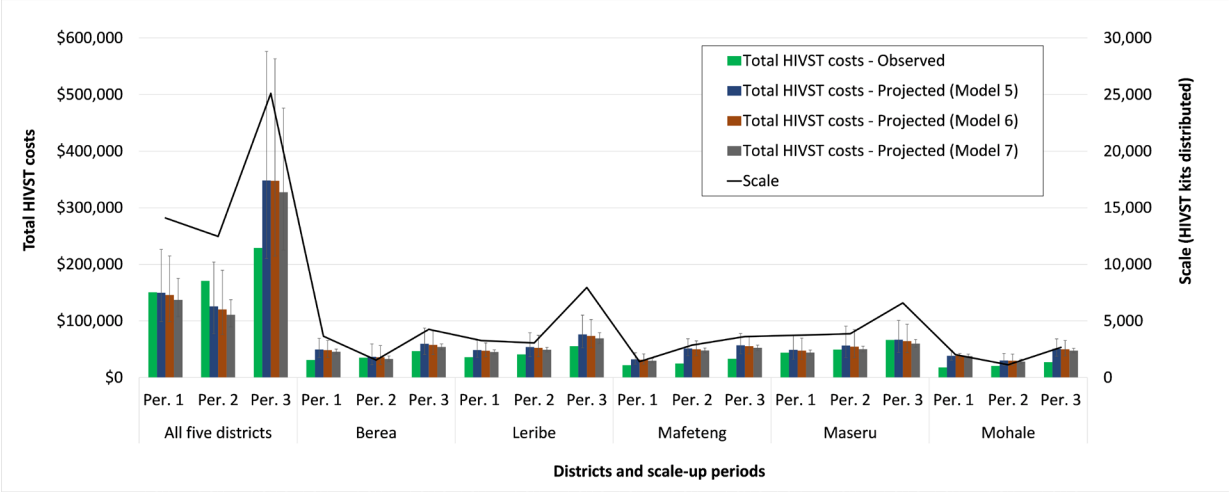

Figure 2 National and district level observed and projected (*models 5–7*) HIVST total costs by scale-up period in Lesotho (error bars: 95% CIs). HIVST, HIV self-testing.

for epidemics such as HIV or malaria where testing efforts have increased over decades, making it more expensive to reach the last percentage of the target population, due to the last remaining untested living in remote areas, or being part of harder to reach population groups.

Our model simplification approach showed that we could use a more parsimonious model to predict costs without significantly losing accuracy. This is particularly relevant as in most studies, we have scant opportunity to collect large amounts of location-specific cost data, and the necessary background information (eg, percentage of population who never tested at the community level) might not exist. The per capita GDP variable showed that our cost function could potentially be applied to other countries. This is in line with the study by Cerecero-García and colleagues[49] that used per capita GDP as a determinant to predict HIV treatment average costs in out-of-sample countries. The extrapolation of cost projections to other Southern African countries seems possible with our parsimonious empirical cost function; however, it would probably require additional or different variables in other settings such as in West Africa.

The use of ECF to predict costs at scale in the context of financial planning and budgeting is limited in the development economics literature.[14 18 50 51] In a study from 2018, Berman and colleagues[18] used a combination of ECF and ACF (using the normative costing approach incorporated in the WHO's OneHealth tool) to provide low and high estimates of financial needs to plan Ethiopia's primary healthcare system. The authors suggested that ECF could provide a low estimate of resource needs due to limited inclusion of capital investments, future changes in services offered to meet changes in health needs and future improvements potentially required for the quality of services provided. Their findings suggest that our cost projections based on ECF could potentially underestimate the amount of resources needed.

Our findings in Lesotho for the observed cost analysis across scale-up periods are consistent, in terms of average costs and cost composition, with the existing literature on HIVST costs in the region, ranging from US$8.15 per kit distributed in Malawi to US$16.42 in Zambia.[12 19] This suggests that they can be used as comparators with forecast costs analysis. Overall, ECF gave highly accurate and consistent scale-up cost estimates compared with observed costs at district level, suggesting a good predictive capacity of our empirical cost function. At higher scale (national level), cost predictions were close to observed costs in period 1 but were slightly below observed costs in period 2 and above in period 3. HIVST implementation and scale-up in Lesotho went through varying levels of efficiency (ie, number of HIVST kits distributed by agents monthly) and was explained by an HIVST implementation strategy maturing over time with important impact on programme costs.[19] HIVST scale-up went through an inefficient phase in period 2 with limited HIVST distribution volumes because of the time spent by providers to offer individual onsite counselling and supervision for self-testing at the mobile outreach. Period 2 was then followed by a more efficient phase, when self-testing booth were introduced at the mobile outreach (period 3) allowing staff to supervise onsite self-testing of many clients at the same time. Although we account for efficiency as a cost determinant in our models 5–7, it was not significant, maybe related to our relatively small sample size or the small role that distributor salaries play in overall costs. Additionally, our ECF is highly sensitive to scale (strongest cost driver), explained by observed large economies of scale in our country sample (Malawi, Zambia and Zimbabwe),[12] which is why the 'efficiency' effect is only observed at larger scale (national and not district level). Consequently, during the inefficient period 2, our projected costs are underestimating observed costs (predicting higher economies of scale than actually observed) and vice versa in period 3.

Our study has several limitations. First, although we use primary data and standardised cost data collection and analysis methods, we have an unbalanced sample of sites. While some countries contributed with a large sample of sites, others only included a few observations. We assume that because the same implementer (PSI) is working in the region with similar financial reporting system, this unbalance would not affect our modelling approach. Second, we use an observed scale-up period in Lesotho that evolved over time as programme matures, limiting our assessment of cost projections' accuracy. Third, we do not have country-specific panel data; therefore, time-dependent unobserved cost determinants are ignored for the econometric analysis. Fourth, while these estimates provide some likely key drivers of costs and their direction, we do expect our cost projections to be more accurate within settings where the main change relates to variations in scale. Fifth, our cost analysis is limited to average costs per kit distributed as the private nature of the HIVST did not allow us to estimate the costs of identifying new HIV-positive individuals or those HIV-positive individuals linked to treatment through HIVST, limiting the applications of our findings by policymakers and programme planners.

Our empirical analysis adds to the discussion on the trade-off between simplicity versus accuracy in cost projection method. Further research should estimate health intervention costs at scale using the three different cost function methods (SCM, ECF and ACF) and compare cost predictions at various scales, ultimately to inform the choice of a cost projection method based on the intended use of the cost estimates.

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