Factors associated with medical consumable availability in level 1 facilities in Malawi: a secondary analysis of a facility census

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Summary

Background Medical consumable stock-outs negatively affect health outcomes not only by impeding or delaying the effective delivery of services but also by discouraging patients from seeking care. Consequently, supply chain strengthening is being adopted as a key component of national health strategies. However, evidence on the factors associated with increased consumable availability is limited.

Methods In this study, we used the 2018–19 Harmonised Health Facility Assessment data from Malawi to identify the factors associated with the availability of consumables in level 1 facilities, ie, rural hospitals or health centres with a small number of beds and a sparsely equipped operating room for minor procedures. We estimate a multilevel logistic regression model with a binary outcome variable representing consumable availability (of 130 consumables across 940 facilities) and explanatory variables chosen based on current evidence. Further subgroup analyses are carried out to assess the presence of effect modification by level of care, facility ownership, and a categorisation of consumables by public health or disease programme, Malawi's Essential Medicine List classification, whether the consumable is a drug or not, and level of average national availability.

Findings Our results suggest that the following characteristics had a positive association with consumable availability— level 1b facilities or community hospitals had 64% (odds ratio [OR] 1·64, 95% CI 1·37–1·97) higher odds of consumable availability than level 1a facilities or health centres, Christian Health Association of Malawi and private-for-profit ownership had 63% (1·63, 1·40–1·89) and 49% (1·49, 1·24–1·80) higher odds respectively than government-owned facilities, the availability of a computer had 46% (1·46, 1·32–1·62) higher odds than in its absence, pharmacists managing drug orders had 85% (1·85, 1·40–2·44) higher odds than a drug store clerk, proximity to the corresponding regional administrative office (facilities greater than 75 km away had 21% lower odds [0·79, 0·63–0·98] than facilities within 10 km of the district health office), and having three drug order fulfilments in the 3 months before the survey had 14% (1·14, 1·02–1·27) higher odds than one fulfilment in 3 months. Further, consumables categorised as vital in Malawi's Essential Medicine List performed considerably better with 235% (OR 3·35, 95% CI 1·60–7·05) higher odds than other essential or non-essential consumables and drugs performed worse with 79% (0·21, 0·08–0·51) lower odds than other medical consumables in terms of availability across facilities.

Interpretation Our results provide evidence on the areas of intervention with potential to improve consumable availability. Further exploration of the health and resource consequences of the strategies discussed will be useful in guiding investments into supply chain strengthening.

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Introduction

Access to medicines is an essential component of universal health coverage.[1] However, stock-outs of essential medicines disproportionately affect low-income and middle-income countries, limiting the capacity of the health-care systems to deliver health care. One analysis[2] of health-care facility surveys in Ghana, Kenya, and Uganda, found that, on the day of survey, most facilities were stocked out of nearly 25% of essential medicines. For certain disease programmes, such as mental health programmes, drug availability has been recorded to be even lower. For instance, one study in seven low-income and middle-income countries between 2012 and 2018, found only 46·1% and 8·2% of facilities had stocks of

Research in context

Evidence before this study
On Sept 7, 2022, we searched PubMed for research articles published from 2000 to 2022 using broad search terms—("drug" OR "consumable" OR "medicine") AND ("stock-out" OR "stockout" OR "availability") AND ("determinants" OR "factors" OR "regression")—in addition to country filters for sub-Saharan Africa. After filtering based on relevance using titles, 33 of 335 papers remained, of which only 15 papers discussed factors associated with stock-outs. Of these, seven papers were either descriptive or qualitative and one assessed the effect of a provider sensitisation intervention on consumable availability. Among the seven studies using regression analysis to determine factors associated with stock-outs, four were limited to a single programme and one grouped facilities by level of care. Only Masters and colleagues and Wagenaar and colleagues carried out a cross-cutting facility-level analysis consisting of 50 and 15 tracer consumables, respectively.

Added value of this study
This study uses facility census data from Malawi (ie, 940 facilities, 130 consumables, and almost 80 facility features), to determine factors associated with consumable availability. We found that higher consumable availability is observed in the higher-level facilities, in those that have a computer, in those that have pharmacists in charge of managing drug orders, in those that have appropriate drug restocking frequency, and in those that are closer to the corresponding regional administrative office. Further, consumables prioritised by the country's essential medicines list (than those with lower priority) and medical consumables (rather than drugs) had better availability across facilities.

Implications of all the available evidence
Some potentially favourable interventions to improve consumable availability at facilities in Malawi are: improving management of and access to drugs for health centres (ie, low-level health facilities), providing facilities with computers for planning and management, improving qualifications of personnel in charge of managing drug orders, establishing appropriate restocking frequency, and improving coordination with facilities further from the regional administrative office. Our results also provide direction for further investigation into the causal pathways underlying these findings and guidance to generate further value-for-money estimates of various supply chain strengthening options.

amitriptyline and diazepam, respectively.[3] While there have been recorded instances of nationwide shortages of medical consumables[4,5] (hereafter referred to as consumables), a common finding across studies is the presence of substantial heterogeneity across facilities within countries.[2,3,6,7] Another common finding is the higher availability but lower affordability of drugs at private facilities than public facilities.[8,9] Regular stock-outs of medicines not only limit the health-care system's ability to deliver services directly affecting health outcomes[7,10] but also discourage patients from seeking health care[11–13] and can even lead to an increase in drug prices.[14]

Countries are increasingly incorporating supply chain strengthening as a key component in their overall strategy to improve population health outcomes[15,16] in recognition of the importance of timely availability of consumables. These strategies are broadly focused on improving information systems, governance structures, storage, and distribution arrangements, and improving the capacity of the supply chain management workforce. While there seems to be consensus that these strategies would improve consumable availability, there is limited evidence on facility-level characteristics associated with high stock-out rates and their relative importance, a key piece of strategic information to guide any investment. Most studies that carry out inferential analysis on the determinants of stock-outs are limited to specific programmes or drugs[7,17–19] or to very few facilities.[6,20,21]

We found only two studies that were based on a dataset capturing multiple disease programmes that investigated the facility-level determinants of stock-outs in the sub-Saharan African region. Masters and colleagues[2] analysed survey data on the availability of 50 drugs across a representative set of facilities in three countries—Ghana, Kenya, and Uganda. They found that the presence of a vehicle, the presence of a laboratory, and proximity to the capital had a positive effect on drug availability whereas the presence of pharmacists and the person in charge of maintaining drug records were not found to have significant effects. Wagenaar and colleagues[6] analysed the availability of 15 essential medicines across facilities in Sofala province, Mozambique and found that facilities closer to the drug distribution warehouses and with a larger number of staff were less likely to suffer from drug stock-outs. These results suggest that more contextual evidence is needed on factors associated with consumable stock-outs to be able to design an effective strategy to improve supply.

Our study is focused on Malawi, a country where most of the population accesses health care at either public or faith-based facilities.[22] Malawi has had a prioritised list of medicines called the Essential Medicine List,[23] which is and has been revised by the Ministry of Health and Population every 5 years since 1987, which are intended to be provided for free to the population. The institution responsible for procuring and distributing these consumables to health facilities is the Central Medical Stores established by the Government of Malawi in 1968. Due to reports of frequent consumable stock-outs, the semi-autonomous institution was converted to a fully

autonomous trust—the Central Medical Stores Trust—in 2011.[21] However, the problem of frequent stock-outs of essential medicines continues to affect the system.[24]

In this study, we aimed to use facility census data from Malawi to identify factors associated with better consumable availability at level 1 health facilities, which comprise the majority of health facilities in the country and in which a majority of the health-care appointments are delivered. Level 1 health facilities are defined by WHO as "rural hospital(s) or health centre(s) with a small number of beds and a sparsely equipped operating room (OR) for minor procedures".[25] To our knowledge, this is the first study analysing consumable availability across different public health or disease programmes (hereafter referred to as programmes) using a census dataset from sub-Saharan African.

Methods

Data sources

The 2018 Harmonised Health Facility Assessment (HHFA) was the primary data source for our secondary analysis. The HHFA is a census of all 1106 health facilities in Malawi covering private-for-profit, private not-for-profit (non-governmental organisations), and government-owned facilities. It provides detailed data on facility characteristics such as location, infrastructure, amenities, services offered, governance, management practices, and leadership as well as the availability on the day of the survey of more than 160 consumables (we use the word survey to describe the HHFA in the subsequent sections in keeping with the terminology used by the Malawi Ministry of Health and Population). The reported availability of each individual consumable was recorded as a categorical variable, which was converted into a binary variable (1 if the consumable is available and 0 if not) for the purpose of our analysis (appendix 1 p 4). We also tested the sensitivity of our results by recoding instances, for which the consumable was reported by the facility-based respondent as available but observed by the surveyor as not available or 0. In the subsequent sections, we use consumable availability to refer to the value of this binary variable as 1.

The HHFA contains data on several types of health facilities, which can be categorised by level of care as follows—community level (ie, health posts managed by community health workers), level 1a (ie, dispensaries, maternities, health centres, and clinics), level 1b (ie, rural, community, and other hospitals), district-level referral centres (ie, district hospitals), and national referral centres (ie, central hospitals). The categorisation of level 1 facilities into 1a and 1b follows that used by She and colleagues.[26] Additionally, HHFA includes the Zomba Mental Hospital, which falls outside these categories and is the only national referral centre for mental health services. Our analysis focused on level 1 health-care facilities (869 at level 1a and 71 at level 1b), which comprised 89% of all facilities reporting to the HHFA. We excluded other levels of care due to limited

	Location(s) of study
Features positively associated with consumable availability	
Use of information computer technology in managing medicine supply[19,27]	Kenya and Ethiopia
Staff qualifications (pharmacy technologists, supply management professionals, general administration professionals)[19,27]	Kenya and Ethiopia
Supply chain design (early warning system)[27]	Kenya
Strong monitoring and oversight mechanism (transparency in procurement of medicines)[19,27]	Kenya
District per capita income[7]	South Africa
Presence of vehicle[2]	Ghana, Kenya, and Uganda
Presence of a lab[2]	Ghana, Kenya, and Uganda
Source of drugs (private)[2]	Ghana, Kenya, and Uganda
Number of health facility staff[6]	Mozambique
Pull system (as opposed to a push system)*[20]	Uganda
Funds (credit line with supplier)†[20]	Uganda
Transport availability†[20]	Uganda
Staff training in drug quantification and pull system†[20]	Uganda
Consumables and medical supplies (as opposed to drugs)[20]	Uganda
Whether the drug is classified as essential in the country's essential medicine list[28]	Multi-country
Features negatively associated with consumable availability	
Ownership (faith-based organisation)[29,30]	Malawi and Rwanda
Rurality[17]	Ghana and Kenya
Distance from the capital[2]	Ghana, Kenya, and Uganda
Distance from drug storage warehouse[6]	Mozambique

*A pull system is when health facilities determine the types and quantities of consumables they need, and a push system is when the consumable needs of health facilities are determined centrally. †Based on a qualitative study.

Table 1: Determinants of consumable stock-outs from literature based in sub-Saharan Africa

variation in facility features across these levels and a limited number of facilities to analyse. The facilities in the analysis each fall under the jurisdiction of one of the District Health Offices (appendix 1 p 5). We excluded consumables for which the HHFA recorded responses from less than 10% of the level 1 facilities, probably because these are not usually stocked at these facilities. We did not include second-line antiretrovirals, which are available in less than 3% of the health facilities.

The study relies upon secondary data and does not involve any personally identifiable information. No primary data collection was undertaken and secondary data were accessed and used with the consent of the Ministry of Health and Population, Malawi.

Statistical analysis

Equation one represents the basic fixed effects logistic regression model run to identify the characteristics associated with consumable availability. The explanatory variables in the equation are factors that have been

Panel: Description of outcome and explanatory variables included in equation one in the regression analyses

Outcome
- Consumable available: binary outcome variable representing whether a consumable was available at a facility on the day of the survey

Explanatory variables
- Facility level: level of health care (level 1a or level 1b); this categorisation of WHO's level 1 facilities into two sub-categories is because of She and colleagues'[26] work
- Facility owner: government, Christian Health Association of Malawi, non-governmental organisation (other than Christian Health Association of Malawi), and private-for-profit
- Urban: whether the facility is based in an urban location (reference level is rural)
- Computer: whether the facility has a functional computer
- Emergency vehicle: Whether the facility has a functional emergency vehicle (this variable is used to capture the presence of a vehicle, which has previously been identified as a factor influencing consumable availability)[2]
- Diagnostic services: whether the facility has a functioning laboratory
- Person in charge of drug orders: drug store clerk, centre manager or owner, clinical officer, health surveillance assistant or senior health surveillance assistant, medical assistant, nurse, pharmacist or pharmacy technician, pharmacist assistant, and other
- Distance from district health office: distance of the facility from the corresponding district health office, the sub-national authority in charge of managing the district-level health-care budget for consumables; this continuous variable is converted into a categorical variable (0–10 km, 11–25 km, 26–50 km, 51–75 km, and >75 km)
- Distance from regional medical store: distance of the facility from the corresponding regional medical store, the Central Medical Stores Trust warehouse from which stocks of drugs are supplied to facilities;[32] this continuous variable is converted into a categorical variable (0–10 km, 11–50 km, 51–100 km, 101–200 km, and >200 km)

- Drug order fulfilment frequency: number of times drugs were restocked at the facility in the 3 months before the survey
- Facility controls: other facility features included in the regression based on bidirectional stepwise selection rather than current literature—functional refrigerator available, functional landline available, functional mobile available, functional toilet available, functional handwashing facilities available, main source of water, only outpatient services offered, HIV services offered, sexually transmitted infection services offered (other than HIV), malaria services offered, tuberculosis services offered, family planning services offered, integrated management of childhood illness services offered, drug suppliers include non-governmental organisations, drug suppliers include private sources, facility directly involved in drug transport, and regional medical store
- Essential medicines list classification (appendix 1 p 6): this is a binary variable representing whether the consumable is classified as vital (value=1) or other (value=0) as per the therapeutic code in Malawi's 2015 Essential Medicine List;[23] vital drugs are those for which procurement and distribution are prioritised because they are identified as having the following characteristics; are potentially lifesaving, have substantial withdrawal side-effects making regular supply mandatory, are of major importance for public health
- Consumable type (appendix 1 p 6): this is a binary variable representing whether the consumable is a drug or other type of consumable; a consumable was classified as a drug if it is ingested or injected and as another consumable if it is a test or is used or applied externally
- District (appendix 1 p 5): the district in which the facility is located; one of 29 public health jurisdictions
- Programme: this represents the public health or disease programme or category within which each consumable falls; general, acute lower respiratory infections, child health, contraception, expanded programme on immunisation, HIV, malaria, non-communicable diseases, obstetric and newborn care, other (infection prevention), surgical, and tuberculosis

identified as determinants of stock-outs by current literature (table 1). Some determinants of stock-outs could not be included in our analysis due to data limitations; this includes number of staff[6] (available only for a subset of health facilities), supervision and oversight[27,31] (data on supervision of pharmacists unavailable), and credit arrangements with the supplier (data not available).[20] The panel provides a description of all the variables in equation one. Further, we included an additional vector of facility features (other than those chosen based on current literature) from the HHFA dataset as control variables to mitigate the effects of omitted variable bias. We identified 64 facility features (in addition to explanatory variables in equations one and two) with response rates higher than 90% as candidates for inclusion in the regression model as

control variables (appendix 1 p 12). 20 features with high collinearity (correlation coefficient >0·8) or low variability across facilities (based on visual inspection) were then not included in the list and, from the remaining 44, the final set of 17 control covariates (facility controls in equation one) included in the model was selected using the bidirectional stepwise procedure applied using the MASS package[33] on R (version 4.2.0). The bidirectional stepwise procedure sequentially adds (and removes) regressors to (and from) the minimum model based on the effect of the addition (and removal) of variables on the Bayesian Information Criterion value of the model, with the objective of minimising the Bayesian Information Criterion value. By penalising the number of parameters estimated by the model, this approach favours a parsimonious model over a complex

one.[34] The literature-based explanatory variables (table 1) were treated as the minimum regressor set, not subject to stepwise selection. The full list of variables considered along with the reasons for the exclusion of those, which were not included in models 2–4, can be found in the appendix 1 (p 12).

Equation one is as follows:

$$Consumable\ available_{d,f,p,i}$$
$$= \alpha_0 + \beta_1 facility\ level_{f,i} + \beta_2 facility\ owner_{f,i} + \beta_3 urban_{f,i}$$
$$+ \beta_4 computer_{f,i}$$
$$+ \beta_5 emergency\ vehicle_{f,i} + \beta_6 diagnostic\ services_{f,i}$$
$$+ \beta_7 incharge\ of\ drug\ orders_{f,i}$$
$$+ \beta_8 distance\ from\ district\ health\ office_{f,i}$$
$$+ \beta_9 distance\ from\ regional\ medical\ store_{f,i}$$
$$+ \beta_{10} drug\ order\ fulfilment\ frequency_{f,i}$$
$$+ \beta_{11} essential\ medicine\ list\ classification_{f,i}$$
$$+ \beta_{12} consumable\ type_{f,i} + \theta facility\ controls_{f,i} + \pi_p + \delta_d + \varepsilon$$

Where d is district, f is facility, p is programme, i is consumable (item), α_0 is the intercept (log odds of consumable availability at baseline values of all other variables), π_p are the programme fixed effects, δ_d are the district fixed effects, and ε is the error term.

We further try to remove the effect of clustering of outcomes by facility and consumable by using a multi-level logistic regression model with random effects,[35] as shown in equation two.

$$Consumable\ available_{d,f,p,i}$$
$$= \alpha_0 + \beta_1 facility\ level_{f,i} + \beta_2 facility\ owner_{f,i} + \beta_3 urban_{f,i}$$
$$+ \beta_4 computer_{f,i} +$$
$$\beta_5 emergency\ vehicle_{f,i} + \beta_6 diagnostic\ services_{f,i}$$
$$+ \beta_7 in\ charge\ of\ drug\ orders_{f,i}$$
$$+ \beta_8 distance\ from\ district\ health\ office_{f,i}$$
$$+ \beta_9 distance\ from\ regional\ medical\ store_{f,i}$$
$$+ \beta_{10} drug\ order\ fulfilment\ frequency_{f,i}$$
$$+ \beta_{11} essential\ medicine\ list\ classification_{f,i}$$
$$+ \beta_{12} consumable\ type_{f,i} + \theta facility\ controls_{f,i} + \varepsilon_{d|f} + \varepsilon_{p|i} + \varepsilon$$

Where $\varepsilon_{d|f}$ are the district and facility random effects and $\varepsilon_{p|i}$ are the programme and consumable random effects.

Table 2 provides a summary of the models that were estimated—model 1 (equation one without facility controls and programme and district fixed effects), model 2 (equation one), model 3 (equation two without programme and consumable random effects), and model 4 (equation two). The regression analyses were performed using the glmmTMB package[36] on R (version 4.2.0).

For ease of interpretation, we exponentiated the regression coefficient estimates to obtain the odds ratios (ORs). We focused on factors for which the 95% CI for the odd ratio did not include the value 1.

To show the validity of our models and choose the primary model to focus on for results, we calculated the predictive accuracy of each model using k-fold

	Model 1, equation one (without facility controls)	Model 2, equation one	Model 3, equation two (without $\varepsilon_{p|i}$)	Model 4, equation two
Facility controls	No	Yes	Yes	Yes
District fixed effects	No	Yes	No	No
Programme* fixed effects	No	Yes	Yes	No
District and facility random effects	No	No	Yes	Yes
Programme and consumable random effects	No	No	No	Yes

*Public health or disease programme within which each consumable falls—general, acute lower respiratory infections, child health, contraception, expanded programme on immunisation, HIV, malaria, non-communicable diseases, obstetric and newborn care, other (infection prevention), surgical, and tuberculosis.

***Table 2:** Specification of different regression models estimated*

	N	Percent	Mean (consumable available)	Odds ratio	95% CI	p value*
All†	940	100·00%	52·39%	..	..	..
Facility level						
Level 1a	869	92·45%	50·71%	Ref	Ref	Ref
Level 1b	71	7·55%	70·91%	2·37	2·26–2·48	<0·0001
Facility owner						
Government	443	47·13%	49·69%	Ref	Ref	Ref
Christian Health Association of Malawi	153	16·28%	62·89%	1·72	1·66–1·78	<0·0001
Non-governmental organisation	109	11·60%	50·60%	1·04	1·00–1·08	0·0818
Private-for-profit	235	25·00%	50·94%	1·05	1·02–1·08	0·0014
Facility is urban						
No	638	67·87%	51·71%	Ref	Ref	Ref
Yes	302	32·13%	54·04%	1·10	1·07–1·13	<0·0001
Functional computer available						
No	608	64·68%	47·65%	Ref	Ref	Ref
Yes	332	35·32%	60·97%	1·72	1·67–1·76	<0·0001
Person in charge of drug orders						
Drug store clerk	28	2·98%	51·74%	Ref	Ref	Ref
Centre manager or owner	42	4·47%	52·21%	1·02	0·93–1·11	0·6833
Clinical officer	173	18·40%	51·65%	1·00	0·93–1·07	0·9177
Health surveillance assistant or senior health surveillance assistant	14	1·49%	36·10%	0·53	0·46–0·6	<0·0001
Medical assistant	294	31·28%	47·44%	0·84	0·78–0·9	<0·0001
Nurse	123	13·09%	54·14%	1·10	1·02–1·19	0·0123
Other	17	1·81%	45·45%	0·78	0·69–0·87	<0·0001
Pharmacist or pharmacy technician	76	8·09%	69·91%	2·17	2·00–2·35	<0·0001
Pharmacy assistant	173	18·40%	54·00%	1·10	1·02–1·18	0·0138
Emergency vehicle available						
No	658	70·00%	49·88%	Ref	Ref	Ref
Yes	282	30·00%	58·09%	1·39	1·36–1·43	<0·0001
Diagnostic services available						
No	35	3·72%	36·53%	Ref	Ref	Ref
Yes	905	96·28%	52·87%	1·95	1·81–2·1	<0·0001

(Table 3 continues on next page)

	N	Percent	Mean (consumable available)	Odds ratio	95% CI	p value*
(Continued from previous page)						
Distance from district health offices						
0–10 km	242	25·74%	53·92%	Ref	Ref	Ref
11–25 km	210	22·34%	52·39%	0·94	0·91–0·97	0·0007
26–50 km	269	28·62%	52·37%	0·94	0·91–0·97	0·0002
51–75 km	160	17·02%	51·64%	0·91	0·88–0·95	<0·0001
>75 km	59	6·28%	49·13%	0·83	0·78–0·87	<0·0001
Distance from regional medical store						
0–10 km	128	13·62%	55·84%	Ref	Ref	Ref
11–50 km	172	18·30%	51·39%	0·84	0·80–0·87	<0·0001
51–100 km	269	28·62%	52·29%	0·87	0·83–0·9	<0·0001
101–200 km	272	28·94%	51·31%	0·83	0·80–0·87	<0·0001
>200 km	99	10·53%	53·33%	0·90	0·86–0·95	0·0001
Drug order fulfilment frequency						
1	192	20·43%	50·95%	Ref	Ref	Ref
2	151	16·06%	51·00%	1·00	0·96–1·04	0·9217
3	391	41·60%	53·77%	1·12	1·08–1·16	<0·0001
≥4	206	21·91%	52·06%	1·05	1·01–1·09	0·0198
Regional medical store						
Centre	354	37·66%	52·66%	Ref	Ref	Ref
North	159	16·91%	50·86%	0·93	0·90–0·96	0·0001
South	427	45·43%	52·75%	1·00	0·98–1·03	0·7964
Functional refrigerator available						
No	167	17·77%	41·70%	Ref	Ref	Ref
Yes	773	82·23%	54·31%	1·66	1·61–1·72	<0·0001
Functional landline available						
No	790	84·04%	51·05%	Ref	Ref	Ref
Yes	150	15·96%	59·87%	1·43	1·38–1·48	<0·0001
Functional mobile available						
No	497	52·87%	49·40%	Ref	Ref	Ref
Yes	443	47·13%	55·77%	1·29	1·26–1·32	<0·0001
Functional toilet available						
No	28	2·98%	45·30%	Ref	Ref	Ref
Yes	912	97·02%	52·61%	1·34	1·25–1·44	<0·0001
Functional handwashing facilities available						
No	551	58·62%	49·71%	Ref	Ref	Ref
Yes	389	41·38%	56·41%	1·31	1·28–1·34	<0·0001
Main water source						
Piped into facility	605	64·36%	55·25%	Ref	Ref	Ref
No convenient water source	22	2·34%	45·12%	0·67	0·61–0·72	<0·0001
Piped onto facility grounds	95	10·11%	46·82%	0·71	0·68–0·74	<0·0001
Protected dug well	9	0·96%	50·00%	0·81	0·71–0·92	0·0013
Public tap or standpipe	17	1·81%	39·35%	0·53	0·48–0·58	<0·0001
Tubewell or borehole	192	20·43%	48·07%	0·75	0·73–0·77	<0·0001
Only outpatient services offered						
No	296	31·49%	58·65%	Ref	Ref	Ref
Yes	644	68·51%	49·10%	0·68	0·66–0·70	<0·0001
HIV services offered (ie, testing or treatment or both)						
No	265	28·19%	45·06%	Ref	Ref	Ref
Yes	675	71·81%	54·73%	1·47	1·43–1·52	<0·0001
						(Table 3 continues on next page)

cross-validation. This approach involves randomly dividing the dataset into k groups, or folds, of approximately equal size. This is followed by iteratively fitting the model on k-1 folds and estimating the predictive accuracy of each fitted model on the hold out group or validation set.[37] We took k=10 and reported the average prediction accuracy and SE across the 10 folds.

Finally, to evaluate any effect modification by the factors associated with consumable availability and key variables, we performed subgroup analyses for which the regression analysis was repeated systematically within each of the following groups—level of care, facility ownership, programme, type of consumable, Essential Medicine List classification of consumable, and consumables grouped by average national availability. Note that some control variables and higher-level random effects could not be included in these models due to challenges with model convergence as a result of high collinearity. Further, for subgroup analyses by programme, we included consumable fixed effects rather than random effects due to the small number of groups (consumables) within each programme.[38]

The distance variables in the panel estimated the shortest distance by road between the facilities and the two reference points, namely the corresponding regional medical store from where consumables are supplied to each facility and the district health office, which acts as the link between health facilities and the Central Medical Stores Trust. These were calculated using the GoogleMaps package[39] on Python 3.8. The link to analysis scripts is provided in the appendix 1 (p 3).

Role of the funding source
The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of this report.

Results
The 940 facilities in the analysis each fall under the jurisdiction of one of the 29 District Health Offices (appendix 1 p 5). Of 162 consumables included in the HHFA, we did not include 29 consumables for which the HHFA recorded responses from less than 10% of the level 1 facilities, probably because these are not usually stocked at these facilities. We did not include a further three second-line antiretrovirals, which are available in less than 3% of the health facilities; 130 consumables were included in the regression analysis (appendix 1 pp 6–11, 14).

Table 3 provides a summary of consumable availability by facility feature and consumable category along with the ORs based on univariate logistic regression models. The average recorded availability across consumables and facilities included in the analysis was 52·39%. Average consumable availability by district ranges from 45·71% to 58·53% with Neno, Salima, Zomba, Balaka, Lilongwe, Rumphi, and Phalombe in the top quartile.

130 consumables were included in our analysis, with average availability ranging from 1·19% for chloroquine to 99·89% for disposable syringes (appendix 1 p 6).

The regression results for models 1–4 are presented in appendix 1 (p 15). The k-fold cross validation results for the four models estimated are also in appendix 1 (p 21). Model 4 (with facility and consumable random effects) is the clearly favoured model and so the rest of our discussion is focused on those results.

The forest plot showing the regression results of model 4 for the explanatory variables of interest as shown in the figure, excludes control variables estimates, which can be found in appendix 1 (p 15). Level 1b facilities had 64% (OR 1·64, 95% CI 1·37–1·97) higher odds than level 1a facilities of consumables being available. Christian Health Association of Malawi and private-for-profit health facilities had 63% (OR 1·63, 95% CI 1·40–1·89) and 49% (1·49, 1·24–1·80) higher odds of consumable availability, respectively, compared with government-owned facilities. Availability of a computer was associated with 46% (OR 1·46, 95% CI 1·32–1·62) higher odds of consumable availability than without a computer. Further, management of drug orders by higher-level cadres improved availability. This finding was true particularly for pharmacists or pharmacist technicians who had 85% (OR 1·85; 95% CI 1·40–2·44) higher odds of availability than a drug store clerk and to some extent, clinical officers, centre managers, and nurses who had 40% (1·40, 1·08–1·81), 38% (1·38, 1·02–1·86), and 30% (1·30, 1·01–1·67) higher odds of availability than drug store clerks, respectively. Facilities furthest from their corresponding district health office (at a distance of more than 75 km) had 21% (OR 0·79, 95% CI 0·63–0·98) lower odds of having consumable stocks than facilities within 10 km from the district health office. A non-linear relationship was observed between the number of order fulfilments in the 3 months before the survey and consumable availability. More specifically, facilities with three order fulfilments in the 3 months before the survey presented the highest availability rates, but at 14% (OR 1·14, 95% CI 1·02–1·27) higher odds of availability than one fulfilment in 3 months, this effect was relatively small in magnitude.

In addition to facility characteristics, consumable characteristics also significantly affected consumable availability across health facilities. Drugs had 79% (OR 0·21, 95% CI 0·08–0·51) lower odds of being available than other medical supplies, and consumables classified as vital in the Essential Medicine List had 235% (3·35, 1·60–7·05) higher odds of being available than others.

Finally, we did not find any association between consumable availability and facility rurality, presence of an emergency vehicle, availability of diagnostic services, and distance from the corresponding regional medical store.

To compare programmes, we need to look at results from models 2 and 3 (appendix 1 p 15). Expanded

	N	Percent	Mean (consumable available)	Odds ratio	95% CI	p value*
(Continued from previous page)						
Sexually transmitted infection services offered (other than HIV)						
No	41	4·36%	33·09%	Ref	Ref	Ref
Yes	899	95·64%	53·13%	2·29	2·14–2·45	<0·0001
Malaria services offered						
No	20	2·13%	32·03%	Ref	Ref	Ref
Yes	920	97·87%	52·75%	2·37	2·15–2·62	<0·0001
Tuberculosis services offered						
No	461	49·04%	48·50%	Ref	Ref	Ref
Yes	479	50·96%	55·59%	1·33	1·30–1·36	<0·0001
Family planning services offered						
No	169	17·98%	50·82%	Ref	Ref	Ref
Yes	771	82·02%	52·71%	1·08	1·04–1·11	<0·0001
Integrated management of childhood illness services offered						
No	96	10·21%	46·04%	Ref	Ref	Ref
Yes	844	89·79%	53·00%	1·32	1·27–1·38	<0·0001
Drugs received from non-governmental organisations						
No	796	84·68%	51·52%	Ref	Ref	Ref
Yes	144	15·32%	56·99%	1·25	1·21–1·29	<0·0001
Drugs received from private sources						
No	537	57·13%	50·65%	Ref	Ref	Ref
Yes	403	42·87%	54·98%	1·19	1·16–1·22	<0·0001
District						
Lilongwe	107	11·38%	56·74%	Ref	Ref	Ref
Balaka	17	1·81%	56·90%	1·01	0·91–1·11	0·8961
Blantyre	114	12·13%	52·79%	0·85	0·81–0·90	<0·0001
Chikwawa	36	3·83%	51·57%	0·81	0·76–0·87	<0·0001
Chiradzulu	15	1·60%	50·50%	0·78	0·70–0·86	<0·0001
Chitipa	14	1·49%	52·24%	0·83	0·75–0·93	0·0006
Dedza	44	4·68%	49·60%	0·75	0·70–0·80	<0·0001
Dowa	28	2·98%	53·34%	0·87	0·81–0·94	0·0005
Karonga	23	2·45%	52·64%	0·85	0·78–0·92	0·0001
Kasungu	42	4·47%	45·71%	0·64	0·60–0·69	<0·0001
Likoma	0	..	..	..	..	..
Machinga	25	2·66%	47·98%	0·70	0·65–0·76	<0·0001
Mangochi	53	5·64%	54·25%	0·90	0·85–0·96	0·0014
Mchinji	21	2·23%	51·36%	0·80	0·74–0·88	<0·0001
Mulanje	33	3·51%	52·39%	0·84	0·78–0·90	<0·0001
Mwanza	5	0·53%	50·52%	0·78	0·66–0·92	0·0034
Mzimba North	40	4·26%	47·20%	0·68	0·64–0·73	<0·0001
Mzimba South	36	3·83%	52·22%	0·83	0·78–0·89	<0·0001
Neno	12	1·28%	58·53%	1·08	0·96–1·20	0·1943
Nkhata Bay	25	2·66%	47·92%	0·70	0·65–0·76	<0·0001
Nkhotakota	38	4·04%	51·86%	0·82	0·77–0·88	<0·0001
Nsanje	14	1·49%	52·49%	0·84	0·76–0·93	0·001
Ntcheu	43	4·57%	51·30%	0·80	0·75–0·86	<0·0001
Ntchisi	11	1·17%	51·18%	0·80	0·71–0·89	0·0001
Phalombe	15	1·60%	55·48%	0·95	0·86–1·05	0·3077
Rumphi	21	2·23%	55·94%	0·97	0·89–1·06	0·4651
Salima	20	2·13%	57·50%	1·03	0·94–1·13	0·4977
					(Table 3 continues on next page)	

	N	Percent	Mean (consumable available)	Odds ratio	95% CI	p value*
(Continued from previous page)						
Thyolo	40	4·26%	45·84%	0·65	0·60–0·69	<0·0001
Zomba	48	5·11%	57·29%	1·02	0·96–1·09	0·4946
All‡	144	100·00%	51·06%	..	..	..
Programme						
General	18	12·50%	56·89%	Ref	Ref	Ref
Acute lower respiratory infections	10	6·94%	53·01%	0·74	0·70–0·78	<0·0001
Child health	7	4·86%	51·31%	0·79	0·75–0·85	<0·0001
Contraception	13	9·03%	50·55%	0·41	0·39–0·43	<0·0001
Expanded programme on immunisation	7	4·86%	52·17%	5·33	4·83–5·89	<0·0001
HIV	9	6·25%	49·58%	1·82	1·70–1·94	<0·0001
Malaria	10	6·94%	53·59%	0·49	0·46–0·52	<0·0001
Non-communicable diseases	19	13·19%	52·56%	0·21	0·20–0·22	<0·0001
Obstetric and newborn care	24	16·67%	46·02%	0·43	0·41–0·45	<0·0001
Other, infection prevention	10	6·94%	55·51%	1·73	1·63–1·84	<0·0001
Surgical	10	6·94%	56·76%	0·75	0·69–0·80	<0·0001
Tuberculosis	7	4·86%	47·69%	1·4	1·26–1·55	<0·0001
Essential medicine list classification						
Other	45	31·25%	41·39%	Ref	Ref	Ref
Vital	99	68·75%	57·32%	1·90	1·85–1·95	<0·0001
Consumable type						
Other consumable	33	22·92%	64·08%	Ref	Ref	Ref
Drug	111	77·08%	48·75%	0·53	0·52–0·55	<0·0001

*The p value is reported for the result of a univariate logistic regression model with consumable availability as the outcome variable and each of the listed categorical variables as the only independent variable in the model. †For the subsequent variables, columns two and three are in reference to the number and percent of facilities. ‡For the subsequent variables, columns two and three are in reference to the number (N) and percent of consumables.

Table 3: Frequency distributions of variables considered and associations with consumable availability (based on univariate logistic regression model)

programme on immunisation and HIV consumables had the highest probability and non-communicable disease, contraception, and obstetric and newborn care consumables had the lowest probability of being in stock.

We re-ran model 4 with consumables reported as available, not observed and reported available, not seen in the HHFA data recoded as not available (see coding as per column on the value of outcome variable in sensitivity analysis, appendix 1 p 4). We observed that the direction and relative magnitude of associations remains the same for all variables except whether the consumable was a drug or other medical supply (appendix 1 p 22).

From the subgroup analyses, we observed that our estimates of the effect of the following factors are largely consistent across subgroups (characteristic positively associated with consumable availability); level of care (level 1b facilities), facility ownership (Christian Health Association of Malawi and other private facilities), person in charge of the drug orders (pharmacists or pharmacist technicians), availability of a computer, Essential Medicine List classification (consumable classified as

vital), and consumable type (medical supplies or other consumables rather than drugs). Detailed subgroup analysis results can be found in the appendix 1 (pp 23–91).

Discussion

While there is a growing emphasis on investments into supply chain strengthening to improve consumable availability and health outcomes,[15,16] there is limited evidence to guide these investments towards resource-efficient or high-impact avenues.

In this Article, we use facility census data from 940 level 1 facilities in Malawi to estimate a multilevel logistic regression model to assess the relationship between facility and consumable characteristics and consumable availability. Our results broadly align with the results from the two previous multi-programme regression analyses[2,6] from the region. We observe that across facilities and consumables, level of care, ownership, availability of a computer, person in charge of placing drug orders, distance from the corresponding district health office, whether the medical consumable is a drug, and how the consumable is classified in the Essential Medicine List had a strong association with consumable availability. Most of the associations hold across levels of care, several disease and public health programmes, and different categories of consumables, which provides confidence in the reliability of these signals. However, unlike previous studies, we did not find a significant relationship between availability and characteristics such as facility rurality,[17] distance from the consumable warehouse,[6] presence of a vehicle[2] (using presence of an emergency vehicle as proxy), and presence of a laboratory,[2] although there was some indication of a significant association within certain subgroups.

Given our analysis, some potentially effective interventions to improve consumable availability at facilities are—improved management of and access to drugs for health centres (lower-level health facilities), providing facilities with computers for planning and management, improved qualification of personnel in charge of managing drug orders, establishing appropriate restocking frequency, and improved coordination with facilities further from the district health office. In Malawi, only 35% of the level 1 facilities possessed a functional computer, 36% received only one or two drug order fulfilments in the 3 months before the HHFA survey, and 8% of facilities had a pharmacist or pharmacist technician handling medication. Our results provide some indication that targeting these features could have a positive effect on consumable availability.

Notably, our results do not seek to establish causal effect. However, given that many of these relationships hold for consumables with low as well as high average availability at the national level, we believe that causes of consumable stock-outs go beyond the inadequacy of their central procurement. Policy translation requires further deliberation and exploration. For instance, further
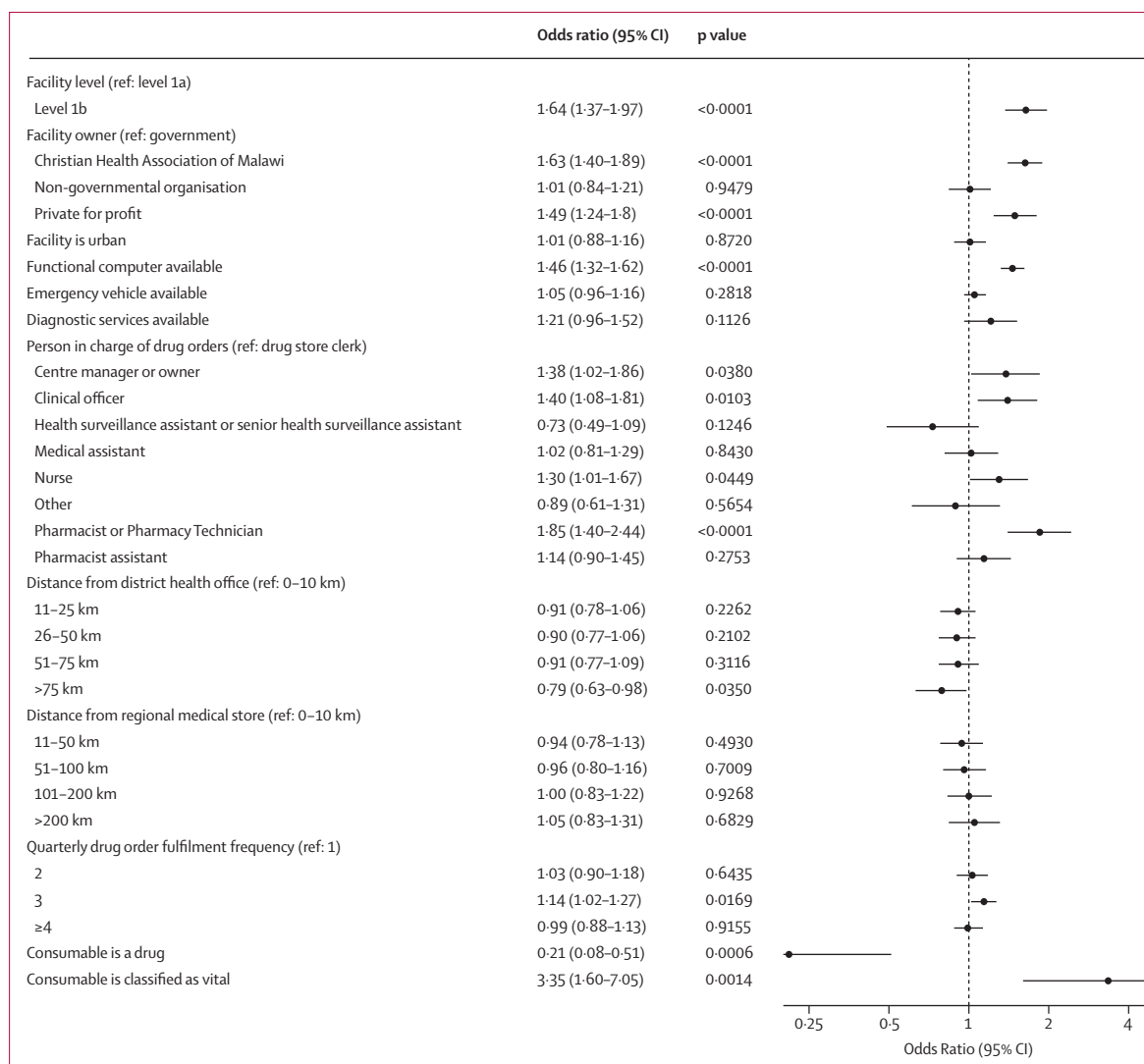
	Odds ratio (95% CI)	p value
Facility level (ref: level 1a)		
Level 1b	1·64 (1·37–1·97)	<0·0001
Facility owner (ref: government)		
Christian Health Association of Malawi	1·63 (1·40–1·89)	<0·0001
Non-governmental organisation	1·01 (0·84–1·21)	0·9479
Private for profit	1·49 (1·24–1·8)	<0·0001
Facility is urban	1·01 (0·88–1·16)	0·8720
Functional computer available	1·46 (1·32–1·62)	<0·0001
Emergency vehicle available	1·05 (0·96–1·16)	0·2818
Diagnostic services available	1·21 (0·96–1·52)	0·1126
Person in charge of drug orders (ref: drug store clerk)		
Centre manager or owner	1·38 (1·02–1·86)	0·0380
Clinical officer	1·40 (1·08–1·81)	0·0103
Health surveillance assistant or senior health surveillance assistant	0·73 (0·49–1·09)	0·1246
Medical assistant	1·02 (0·81–1·29)	0·8430
Nurse	1·30 (1·01–1·67)	0·0449
Other	0·89 (0·61–1·31)	0·5654
Pharmacist or Pharmacy Technician	1·85 (1·40–2·44)	<0·0001
Pharmacist assistant	1·14 (0·90–1·45)	0·2753
Distance from district health office (ref: 0–10 km)		
11–25 km	0·91 (0·78–1·06)	0·2262
26–50 km	0·90 (0·77–1·06)	0·2102
51–75 km	0·91 (0·77–1·09)	0·3116
>75 km	0·79 (0·63–0·98)	0·0350
Distance from regional medical store (ref: 0–10 km)		
11–50 km	0·94 (0·78–1·13)	0·4930
51–100 km	0·96 (0·80–1·16)	0·7009
101–200 km	1·00 (0·83–1·22)	0·9268
>200 km	1·05 (0·83–1·31)	0·6829
Quarterly drug order fulfilment frequency (ref: 1)		
2	1·03 (0·90–1·18)	0·6435
3	1·14 (1·02–1·27)	0·0169
≥4	0·99 (0·88–1·13)	0·9155
Consumable is a drug	0·21 (0·08–0·51)	0·0006
Consumable is classified as vital	3·35 (1·60–7·05)	0·0014

Figure: **Multilevel regression results for model 4 with a binary outcome variable representing the availability of consumables* on the day of the Harmonised Health Facility Assessment survey**

*An odds ratio >1 here represents greater odds of consumable availability.

exploration is needed to understand the reasons for the better performance of Christian Health Association of Malawi and private health facilities in terms of consumable availability so better consumable procurement and management practices can be imported into government facilities, which continue to cater to a majority of the population. Similarly, as Malawi transitions out of parallel supply chains,[24,40] further exploration of what makes the availability of HIV, expanded programmes on immunisation, and tuberculosis consumables, of which parts of the supply chain lies outside the Central Medical Stores Trust, so much higher than programmes more reliant on the Central Medical Stores Trust, would also help with supply chain intervention design.

Our study makes an important contribution towards generating evidence to guide supply chain strengthening investments, but the results have a few limitations. First, since our analysis relies on a one-off census, we are restricted to only 1 year of data (2018–19) and our outcome variable—whether a consumable is available on a given day—relies upon reported rather than observed information. The results of the study can be solidified using time-series administrative data from OpenLMIS covering a wider range of consumables and recorded monthly since 2017;[41] these data would also allow us to capture seasonality in consumable availability. Some determinants of stock-outs[6,31] suggested by previous literature could not be included in our analysis due to a lack of adequate data. Further, although our results are aligned with previous studies from Ghana, Kenya, Uganda, and Mozambique,[2,6] since our own analysis is based on data that come only from Malawi, the external

validity of our results is not guaranteed and requires similar such analyses to be conducted in other countries. Our analysis is also limited to level 1 facilities. Further research is needed to understand consumable availability at facilities providing higher levels of care. Finally, for these results to affect resource allocation decisions, taking the results a step further and quantifying the health impact of the potential increase in consumable availability as a result of specific areas of supply chain strengthening would be important.[42] This combined with the estimated costs of supply chain strengthening interventions will enable the estimation of the value of potential supply chain investments in terms of commonly used cost-effectiveness measures such as cost per disability-adjusted life years averted, allowing for comparability with competing investment options.[43] We plan to implement such an analysis by plugging the outputs of this study into the Thanzi La Onse model[44] of Malawi's health-care system and population to identify the value for money of supply chain investment in the country.

Effective interventions are urgently needed to improve consumable availability at facilities in Malawi. Understanding the determinants of stock-outs can help design and target these interventions in a way that ensures efficiency in the allocation of resources for supply chain strengthening.

Contributors
SM: conceptualisation, methods, data curation, formal analysis, visualisation, and writing the original draft. TDM: conceptualisation, methods, and reviewing and editing the manuscript. TC: conceptualisation, methods, reviewing and editing the manuscript, and funding acquisition. MC and JM-B: reviewing and editing the manuscript and funding acquisition. CC and GK: data curation and reviewing and editing the manuscript. JHC, EJ, BJ, ILL, GM, EM, MM, DN, BS, RMS, WT, and PT: reviewing and editing the manuscript. MMG and AUT: software. PR: conceptualisation, supervision, and funding acquisition. ANP and TBH: conceptualisation, methods, reviewing and editing the manuscript, funding acquisition, and supervision. SM and TBH have accessed and verified the data and were responsible for the decision to submit the manuscript. All the authors had access to the data in the study and they accept responsibility to submit for publication.

Equitable partnership declaration
The authors of this paper have submitted an equitable partnership declaration (appendix 2). This statement allows researchers to describe how their work engages with researchers, communities, and environments in the countries of study. This statement is part of *The Lancet Global Health*'s broader goal to decolonise global health.

See **Online** for appendix 2

Declaration of interests
Besides funding from the Wellcome Trust and UK Research and Innovation going towards authors' institutions, some authors took on private projects, outside the submitted work. SM declares receiving consulting fees from The Global Fund. TC declares consulting fees from the UN Economic Commission for Africa, and non-paid work chairing a Trial Steering Committee for a trial of adolescent mental health interventions in Nepal. ANP declares receiving consulting fees from the Bill & Melinda Gates Foundation. All other authors declare no competing interests.

Data sharing
The data sources used for the study were provided by the Malawi Ministry of Health and Population under the Memorandum of Understanding between institutions engaged under the Thanzi La Onse research programme and are not publicly available. We have tried to include considerable descriptive detail on the underlying data in table 3 and in the appendix (pp 5–11). Access to the full dataset can be requested but will need to be approved by the Malawi Ministry of Health and Population.

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