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Full title:

Technical and scale efficiency in the delivery of maternal and child health services in Zambia: A district-based data envelopment analysis

Short Title:

Technical and scale efficiency in Zambia

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Abstract

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Objective: Despite tremendous efforts in scaling-up key maternal and child health interventions in Zambia, progress has not been uniform across the country. This raises fundamental health system performance questions that require further investigation. Our study investigates technical and scale efficiency in the delivery of maternal and child health services in the country.

Setting: The study focused on all the 72 health districts of Zambia.

Methods: We compiled a district level database comprising of key health system outputs, under-five mortality rate and health intervention coverage, and a set of health system inputs namely, financial resources and human resources for health for the year 2010. We used data envelopment analysis to assess the performance of sub-national units across Zambia, controlling for the effects of female education, household access to electricity, improved cooking methods and levels of donor funding for health actions.

Results: Nationally, average technical efficiency was 62.4% (CI, 57.5%-68.4 %), which suggests huge inefficiency in resource use in the country, but also the potential for expanding services without injecting additional resources to the system. Districts that are more urbanised and have higher proportion of educated women tend to be more technically efficient. Donor funding has insignificant or at best negative effect on efficiency. Pure technical efficiency was positively correlated to health intervention coverage (r=0.52, n=72, p=0.002) and child survival (r=0.65, n=72, p=0.005). Pure technical efficiency and scale efficiency were 87.2% (CI, 84.2%-91.2 %) and 71.4% (CI, 68.4%-74.6 %), respectively.

Conclusion: With the pressing need to accelerate progress in population health, health system stewards must seek efficient ways of delivering services to attain universal health coverage. Understanding the factors that drive performance and seeking ways to enhance efficiency offer a practical pathway through which low-income countries could make progress on population health without necessarily seeking additional resources.

Key words: Technical Efficiency; Scale Efficiency; Data Envelopment Analysis; Health Systems Performance

Strengths and Limitations of Study

- The study measures technical and scale efficiency at the district level, lowest health system management unit in most developing countries
- Data envelopment analysis is used to determine sources of inefficiency in the health system
- The study covers only maternal and child health despite the fact that the health system also encompasses other broader programmatic areas

Introduction

Decentralization of health services has been pivotal in the efforts toward universal health coverage across the developing world [1–3]. There are many drivers of this trend, but improvements in service delivery remains an implicit motivation behind most decentralization efforts [2, 3]. This is mainly anchored around the ideals and principles of local ownership and accountability in service delivery as well as meeting key health system goals with respect to equity, efficiency and responsiveness [1-4].

As in most other countries, Zambia has embraced a decentralized health system model since 1992 as a pathway towards equitable access to health services for its population [3,4]. This entailed devolution of key decision-making and implementation functions to the provincial and district level, where stewards were assigned specific roles aimed at meeting national health policy objectives. Consequently, health resources were directed toward districts which were given primary responsibility in the delivery of key health services to meet various local population health needs [3,5–7].

In this arrangement, the central government is largely focused on setting national priorities and allocating health resources to subnational units, based on projected health needs. In practice, this involves the Ministry of Health (MOH) providing budget ceilings to all district health offices (DHO), which would then make their own plans and budget for their activities in line with local projected health needs, bearing in mind the budget ceiling. The Provincial Health Offices occupies an intermediate position between the national and district levels mainly taking an oversight role for districts nested within their respective jurisdictions [3,5,6]. This approach is aimed at ensuring equity in health service delivery, core health objective of the Government of Zambia [5–8].

Despite these efforts, in-depth investigation of the country's health system performance reveals wide subnational heterogeneity in goal attainment. Invariably, this underscores the need to understand the root cause of the differentials in performance across subsystems so that lessons drawn from high performing sub-units could be informative to those that are lagging behind [3,4,7–9]. A systematic and objective comparison of goal attainment and resource allocation across health sub-units in Zambia is timely. The results could provide a valuable benchmarking framework in the effort to push the country's health systems towards better performance [4,9,10].

In this paper we make a systematic comparison in performance across districts and provinces in Zambia; paying attention to the priority areas of under-five mortality and health intervention coverage for maternal and child health as key health system outputs while human and financial resources allocated to districts, are considered as the health system inputs. Further, we seek to demonstrate how data envelopment analysis (DEA) [11] can be applied for efficiency benchmarking and comparative performance assessment for a decentralised health system.

Methods

The analytical framework proposed here borrows its fundamentals from the World Health Organization (WHO) Health System Framework, which logically links health system inputs to outputs [2–4]. According to the framework, a health system is composed of six discrete pillars working in tandem to meet the expected health goals [2,4,8–10]. In our analysis we have focused on human resources, health financing, health intervention coverage and mortality trends, with the later serving as our main health system outputs. Meanwhile, human and financial resources constitute the input variables underlying the production function used in the estimation of efficiency scores.

In the definition of efficiency, a distinction should be made between technical, allocative, and scale efficiency measures [12]. In this study only technical and scale efficiencies were considered, mainly because cost statistics, needed for the estimation of allocative (i.e., price) efficiency, were not available to us. For estimation of efficiency scores, we employed the Banker, Charnes, and Cooper (BCC) formulation of the DEA model. The choice of the BCC approach is partly guided by the fact that all our variables were ratio-based, and we endeavoured to take economies of scale into account in the analysis. In addition, like all other DEA models, the BCC model also handles multiple inputs and outputs, which is particularly suited for complex fields such as health systems [11,13], where there is a multidimensional mix of input and output variables that have to be considered simultaneously [13,14]. Further, we applied the approach developed by Charnes, Cooper and Rhodes (CCR) to enable us to decompose overall efficiency score into scale and pure technical efficiency.

Given that each decision-making unit (DMU) may face locally unique conditions, the DEA approach assesses each unit separately, assigning some weighted combination of inputs and outputs that maximizes its efficiency score [15]. Algebraically, this is achieved by solving for each DMU (district) the following linear programming problem [15].

$$max_{u,v} \quad \left(\frac{\sum_{o=1}^{o} u_o \times y_{o0}}{\sum_{i=1}^{i} vi \times k_{i0}}\right)$$

$$\text{subject to: } \frac{\sum_{o=1}^{o} u_o \times y_{on}}{\sum_{i=1}^{i} vi \times k_{in}} \leq 1 \quad n = 1, \dots \dots N$$

Where

y_{o0} = quantity of output "o" for DMU_0

u_o = weight attached to output o, $u_o > 0$, o = 1, ……., O

k_{i0} = quantity of input "i" for DMU_0

v_i = weight attached to input i, $v_o > 0$, i = 1, ……., I

The equation is solved for each DMU iteratively (for n=1, 2,…, N), and therefore the weights that maximize the efficiency of one DMU might differ from the weights that maximize the efficiency of another DMU [16]. Theoretically, these weights can assume any non-negative value, while the resulting technical efficiency scores vary only within a scale of 0 to 1, subject to the constraint that all other DMUs also have efficiencies between 0 and 1.

Technically, a DEA-based efficiency analysis can take either an input- or output-orientation. In an input-orientation, the primary objective is to minimize inputs, while in an output-orientation the goal is to attain the highest possible output with the given amounts of inputs. In our case, an output-oriented DEA model was deemed more appropriate on the premise that district health teams have essentially a fixed set of inputs to work with at any given time [3,5,6]. In other words, the district health system stewards would have more leverage in controlling outputs through innovative programming rather than raising additional resources.

As performance and institutional capacity are expected to vary across districts, a variable-returns-to-scale (VRS) approach was also considered more relevant to the study setting [4]. This approach allows for economies and diseconomies of scale, rather than imposing the laws of direct proportionality in input-output relationships as espoused in the constant-returns to scale (CRS) [13,14,16–18]. A VRS model also offers the advantage of decomposing Overall Technical Efficiency into Pure Technical Efficiency (PTE) and Scale Efficiency (SE), which is essential in locating the source(s) of differentials in performance across production units [13,14,16–19].

In our DEA model, two output measures, under-five mortality and health intervention coverage, were used. Because the outputs are measured in such a way that "more is better" we calculated the ratio of under-five children that survived to the number of children that died; as a measure of under-five survival. Health intervention coverage was a composite metric comprising of the proportion of the population in need of a health intervention who actually receive it [4, 8].

The composite metric comprised of DPT3 and measles immunizations, skilled birth attendance, and malaria prevention. For malaria prevention, we included the indicator approximating malaria prevention efforts across districts, i.e. the combination of insecticide treated net (ITN) ownership or indoor residual spraying (IRS) coverage. The average of all the 5 health interventions for each district, was taken as the health intervention coverage [4]. This innovative way of data reduction through combining a range of health interventions has the advantage of reducing the number of variables that enter into the model. This in turn helps to maintain reasonable balance between the number of DMUs and input and output variables which is required to avoid scarcity of adjacent reference observations or “peers,” which if not taken care of would lead to sections of the frontier being unreliably estimated and inappropriately positioned [3,13,14,16–20].

Data Sources

We used data from the Malaria Control Policy Assessment project (MCPA) in Zambia, which generated the most comprehensive district-level under-5 mortality, health intervention coverage and socioeconomic estimates for the country [4,8]. For both indicators, to capture the most recent period for the country, the data representing the year 2010 were used.

For the inputs part, we obtained a dataset of annual operational funds from both government and donors to each of the 72 districts for the year 2010. These data are available through the Directorate of Health Policy and Planning (DHPP) of the Ministry of Health [8]. Using population data from the Central Statistics Office of Zambia, we calculated the total population-adjusted funds disbursed to each district. We further obtained data from the Ministry of Health on the human resource complement for the year 2010 covering the medical professionals (doctors and clinical officers) and nurses (including midwives) for each district and adjusted them for the district population.

In addition, we included the mean years of education among women aged 15-49 years, the proportion of districts funds originating from donors, household access to electricity and the proportion of household with improved cooking methods, as environmental variables that are external to district health units but nonetheless affect performance and efficiency levels of the health system. These variables were chosen based on their importance in addressing the key global health targets around maternal and child health in Africa [1–3]. Donor funding is a major feature in African health systems and has been a subject of major debate in the efforts toward health system strengthening. Similarly, the relationship between health and education, particularly among women, has been variously documented [2–4,8]. Both datasets were obtained from the MCPA database. Analyses were done using R version 3.2.1, specifically the r-DEA package that has the capability to combine the inputs, outputs, and environmental variables into one stage of analysis. To obtain robust estimates, we bootstrapped the model 1,000 times and generated uncertainty around the estimates [18].

Ethical approval

Permission to conduct the study was obtained from the Ministry of Health, Zambia. Since our study only used de-identified secondary data, we were granted exemption from the IRB, University of Zambia: IRB00001131 of IROG000074.

Results

Descriptive statistics

Table 1 presents descriptive statistics for the variables used in the study. The range for both inputs and outputs is quite wide. For example, under-five mortality rate across districts varies between 87.16 deaths per 1000 live births and 161.96 deaths per 1000 live births, while health intervention coverage varies from 44.20% to 93.42%. Similar patterns are apparent for health workforce and financing indicators, where the distribution of nursing personnel ranged from 5.16 nurses/1000 population to 33.03 nurses/1000 population, while total funds to districts ranged from 4.24 million ZMK/1000 population to 23.77 million ZMK/1000 population. This suggests that at the subnational level, the Zambian health system is quite heterogeneous.

Notwithstanding the subnational variation, the national aggregate estimates for Zambia do compare closely with the African regional estimates, further indicating that lessons from this study could be instructive to other countries within the region. For instance, under-five mortality rate for the country compares closely with the African regional average reported on 2008, at 110.9 deaths/1000 live births [21].

Table 1: Summary statistics of the variables

	Variable	Units	Mean	Standard deviation	Min	Max
Outputs	Under-five mortality	*Deaths per 1000 live births*	115.61	(14.66)	(87.16)	(161.96)
	Health intervention[ii] coverage	*Percentage %*	67.09	(10.99)	(44.20)	(93.42)
Inputs	Total funds	*Millions of Zambian Kwacha per 1,000 population*	13.60	(3.55)	(4.24)	(23.77)
	Medical personnel	*Medical personnel[iii] per 1,000 population*	6.96	(3.34)	(.92)	(18.23)
	Nursing personnel	*Nursing personnel[iv] per 1,000 population*	12.72	(5.76)	(5.16)	(33.03)
Environmental	Proportion of donor funds	*Percentage%*	38.43	(5.21)	(31.39)	(57.21)
	Proportion of households with access to electricity	*Percentage%*	13.23	(17.06)	(0.19)	(61.29)
	Proportion of households with improved cooking	*Percentage %*	10.26	(14.55)	(0.33)	(53.77)
	Average years of education for women aged 15-44	Years	5.72	(1.60)	(2.93)	(9.51)

[ii] Health intervention coverage is a composite metric comprising of 5 health interventions
[iii] Medical personnel includes both medical doctors and clinical officers (medical assistants).
[iv] Nursing personnel includes both registered nurses and midwives

Table 2, makes provincial comparisons for all input and output variables, revealing further heterogeneity across the country. For instance, in the predominantly urbanized Copperbelt province, health intervention coverage was as high as 81.05% (CI: 75.31%-86.78%), in comparison to the North-Western province, which was predominantly rural, with a coverage of 61.64% (CI: 53.80%-69.48%). Still within provinces, there was significant heterogeneity, considering that all provincial estimates for health intervention coverage had wide confidence intervals of more than 10% points. This trend further underscores the differences in goal attainment across the districts in country. Similar differences were also observed with respect to under-five mortality where provincial estimates revealed a wide gap across provinces, with the Southern province as the best performer at 101.86 deaths per 1000 live births (CI: 96.37-107.36) and Northern province as the worst performing at 130.18 deaths/1000 live births (CI: 122.62-137.75).

Table 2: Summary of variables across provinces

Provinces	Under-five mortality	Health intervention coverage	Total funds	Medical personnel	Nursing personnel	Districts
Units	*Percentage %*	*Percentage%*	*Millions of Zambian Kwacha per 1,000 population*	*Medical Personnel per 1,000 population*	*Nursing Personnel per 1,000 population*	*Number*
Central	109.46 (103.00, 115.91)	63.92 (54.41, 73.42)	12.70 (11.97, 13.44)	7.75 (5.63, 9.87)	12.02 (6.53, 17.51)	(6)
Copperbelt	111.07 (106.40, 115.75)	81.05 (75.31, 86.78)	10.27 (7.39, 13.16)	8.08 (6.36, 9.80)	16.83 (14.89, 18.77)	(10)
Eastern	126.35 (120.73, 131.97)	69.96 (65.41, 74.50)	14.58 (12.71, 16.46)	6.64 (4.26, 9.02)	10.26 (8.26, 12.27)	(8)
Luapula	127.99 (115.62, 140.36)	62.18 (57.94, 66.43)	15.26 (13.94, 16.57)	5.99 (4.44, 7.54)	10.11 (7.35, 12.88)	(7)
Lusaka	111.76 (101.84, 121.69)	77.00 (71.96, 82.05)	11.26 (2.56, 19.96)	7.65 (4.36, 10.94)	15.59 (3.60, 27.58)	(4)
North-Western	106.64 (101.07, 112.22)	61.64 (53.80, 69.48)	16.52 (14.59, 18.45)	6.89 (3.77, 10.00)	15.98 (10.65, 21.32)	(7)
Northern	130.18 (122.62, 137.75)	62.52 (58.38, 66.67)	13.76 (12.57, 14.96)	3.66 (2.40, 4.93)	8.82 (6.72, 10.93)	(12)
Southern	101.86 (96.37, 107.36)	65.08 (58.06, 72.10)	12.79 (11.49, 14.10)	9.27 (7.05, 11.50)	14.80 (11.66, 17.94)	(11)
Western	110.49 (99.99, 120.99)	62.24 (54.07, 70.42)	15.73 (14.67, 16.79)	7.73 (5.70, 9.77)	11.40 (7.80, 15.01)	(7)

95% confidence intervals in parentheses

Overall efficiency, pure technical efficiency, and scale efficiency

Figure 1, shows the estimates of overall technical efficiency (OTE) scores obtained using an output-oriented bias-corrected DEA model across the 72 districts of Zambia. A value of 1 indicates that a district produces at the frontier; and the lower the value, the farther the district is from the efficient frontier. As with the input and output indicators shown in Table 1, the results shown in Figure 1 portray a deeply heterogeneous picture in terms of overall technical efficiency across subnational units. For example, both the worst and best performing districts, Luangwa, at 31% and Chingola at 91% are found in the predominantly urban provinces of Lusaka and Copperbelt respectively.

Only 23 (31.9 %) districts in the country (predominantly from the Northern, Lusaka and Copperbelt provinces) had efficiency scores above 70%. The next tier of top performers, with an overall technical efficiency score between 60% and 70%, showed a mixed picture but also with predominant representation from the Copperbelt province and other districts from the northern and eastern parts of the country, which suggests a phenomenon of spatial clustering in performance in the country. The average efficiency score for the country as a whole was 62.4% (CI, 57.5%-68.4 %), which suggests a significant potential for further improvement without the need for additional resources. In other words, the country can potentially either reduce current input levels by 37.6% while leaving output levels unchanged or use the existing excess inputs to attain higher levels of output.

The OTE, can be further decomposed into pure technical efficiency (PTE) which is a measure of managerial performance in the production process and scale efficiency (SE) which is the ability to choose the optimum size of resources in production. Figure 2 shows PTE, SE, and OTE scores for the nine provinces of Zambia. OTE appears to be higher in the Northern, Copperbelt and Lusaka provinces. Still the Copperbelt and Lusaka provinces are also in the lead in terms of PTE, while the Eastern and Luapula provinces are at the bottom tier. Meanwhile, SE appears to be greater in Northern and Luapula provinces. In general, the districts and provinces that performed poorly in terms of SE were mostly large and sparsely populated, while the smaller, densely populated ones performed better. Broadly, it can be seen that health system inefficiency in the country is due to both poor input utilization (i.e., pure technical inefficiency) and failure to operate at the most productive scale size (i.e., scale inefficiency).

The results presented in Figure 3 show the distribution of scale inefficiency (or inappropriate size) at the district level in Zambia. The overall picture that emerges from the figure corroborates what was observed from the provincial data and shows that settlement patterns and urbanization seem to be the driving forces behind scale efficiency in the country, with districts that are sparsely populated and have limited infrastructural access suffering from high levels of scale inefficiency.

The efficiency measures discussed above only look into the use of resources or scale of operation and do not directly address outcomes. For instance, it is possible for districts or provinces to have lower service coverage but perform better in the management of resources available to them and vice versa. Figure 4 compares pure technical efficiency and health intervention coverage across the 72 districts of Zambia. The pure technical efficiency scores presented in the figure ensure that the efficiency levels of districts are compared only with districts of roughly similar size and hence provide opportunity for policymakers and local decision-makers to examine the effect of managerial competence without the diluting effects of scale of operation on performance.

In Figure 4, 59 of the 72 districts fall into the high managerial performance category, of which 11 have managed to combine high managerial efficiency with high health intervention coverage. However, in the remaining 48 districts in this category, health intervention coverage is still low despite high efficiency. On the other hand, there are 13 districts, where both managerial performance and coverage remain low. The average pure technical efficiency score was 87.2% (CI, 84.2%-91.2%), while actual scores ranged between 69.1% and 97.3%. Overall there was a positive correlation between health intervention coverage and PTE ($r = 0.52$, $n = 72$, $p = 0.002$).

Figure 5, shows that under-five survival across districts had a strong correlation ($r = 0.65$, $n = 72$, $p = 0.005$) with PTE. It is clear that with the exception of a few outliers such as Chilubi, Luwingu and Kaputa, most of the districts that were in the high performance efficiency region had higher under-five survival rates in comparison to those in the low performance region. This is an expected trend given the role of health system efficiency in ensuring better health outcomes.

Effects of contextual factors on overall technical efficiency

As a part of the two-stage DEA approach, we carried out a regression analysis to estimate the effect of contextual factors on the OTE level of districts. In DEA literature, the influence of these variables is usually analyzed by applying either Tobit or logistic regression models because the distribution of efficiency scores is confined to the interval (0, 1). Table 3 shows Tobit regression-based results obtained using Simar and Wilson's [22] bias-corrected two-stage estimation process for the four environmental variables we chose for our analysis. The results suggest that the channelling of donor funding in Zambia seems to have an insignificant or at best negative effect on technical efficiency. Meanwhile, female education had a significant positive effect, confirming the interdependencies between health and education noted in previous studies.

Table 3: The effects of the environmental variables

	Coefficients
Constant	1.34*
Female education	0.15***
Household access to electricity	-0.03
Proportion of funding from donor sources	-1.16
Household access to improved cooking	0.01

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Discussion

With the push toward universal coverage across the developing world and uncertainties about future global investment on health, the question of efficiency in health service delivery has become increasingly important. This paper attempted to evaluate the extent of pure technical, scale, and overall technical efficiencies in Zambia using cross-sectional data from 72 districts. In addition, an attempt has been made to investigate the role of environmental factors specifically donor funds and maternal education on the efficiency of maternal and child health in the country. This is particularly relevant given the finite nature of available health resources in the face of rising health needs [1,2,4,8]. We have proposed an analytical framework for health system performance assessment with a focus on relative efficiency at the subnational level. This involved an application of a two-stage DEA framework in which the estimates of OTE, PTE and SE for individual districts have been obtained by CCR and BCC models in the first stage; and a Tobit regression model has been used to work out the moderating role of environmental factors on efficiency in the second stage.

DEA is an attention-directing managerial technique [23]. By evaluating the relative efficiency of sub-national units, it locates trouble spots in the service delivery system and potential for further improvement. This is based on the understanding that in a decentralized health system, subnational units have a far-reaching impact on the overall performance of the health system [4,7,9]. Through this framework, policymakers can objectively benchmark the performance of the district health system with the aim of fostering peer learning and accountability.

The study findings reveal significant heterogeneity in performance across districts and provinces that are due to both poor input utilization (i.e., pure technical inefficiency) and failure to operate at the most productive scale size (i.e., scale inefficiency). The average PTE score for the country has been observed to be 87.2%, which implies that 12.8 percentage points of the about 37.6% overall technical inefficiency in the country was due to district health managers who are not following appropriate management practices and are selecting incorrect input combinations. The remaining shortfall in overall inefficiency appears to be due to inappropriate scale of operations. Specifically, urban districts seemed to be more scale-efficient in comparison to their rural counterparts, probably as a result of having a densely populated environment where the marginal cost of increasing population coverage is significantly lower than in rural areas. Similarly, urban residents tend to have better access to health services, both in physical and financial terms, than their rural counterparts, resulting in higher utilization of the available services. In contrast, due to access challenges in rural areas, there is often low utilization of the available health services.

We further demonstrated that the relationship between health system inputs and outputs is complex and showed that 59 of the 72 districts fall into the high managerial performance category, of which eleven have managed to combine high managerial efficiency with high health intervention coverage. In the remaining 48 of the 59 districts in this category, health intervention coverage is still low, but this had nothing to do with the efficiency with which managers combined the inputs at their disposal, suggesting that for this group of districts the only way to improve coverage could be to put additional resources into the system. On the other hand, in the remaining 13 districts, where both PTE and coverage of services remained low, improvements in health intervention coverage should first and foremost focus on improving managerial underperformance (i.e., managerial inefficiency) in organizing the inputs at their disposal, followed by introducing new resources, especially in areas where coverage rates are extremely low.

In health programming it is equally important not to ignore the social determinants of health, particularly the educational status of women, which is shown to have a positive impact on the efficiency of the health care system. Educated women are likely to be aware of and demand appropriate health services when they need them. In fact, the variables that have been included in the composite metric, comprise of skilled birth attendance, childhood immunizations and malaria prevention, all that are considered crucial for a maternal and child health in most of Africa [4]. Therefore, it would only be natural that educated women would have the awareness to seek and utilize these important health services when they are available, in comparison to their less educated counterparts. The cumulative effect at the district level would also translate to higher utilization and therefore efficient service provision in districts where women are more educated.

In as much as donor funding has been a dominant feature of the African health systems landscape in recent years and has contributed significantly to the scale-up of priority health interventions, many have raised questions in terms of its effectiveness [2,24–26]. From this analysis we cast doubt as to whether the donor funds are being channelled and utilized optimally at the district level. There are multiple pathways through which donor funds could adversely affect efficiency at the district level. First, districts with limited institutional capacity might lack the implementation capacity to use the available funds to deliver the required health services effectively. This would lead to inefficiency within the health system, whereby districts will have large amounts of money without the ability to deliver required services. Second, donor funds are often earmarked for specific programs such as malaria, HIV/AIDS, and tuberculosis [3]. In such vertical programming, the donor-funded programs might reduce other health programs' implementation capacity, leading to sub-optimal performance in other key program areas such as skilled birth attendance and other preventive services that are relevant for maternal and child health care.

Our analysis is not, however, without limitations. First, we have only focused on a limited number of health system outputs (i.e., maternal and child health indicators), despite the fact that a health system produces many more outputs covering different programmatic areas. Similarly, due to data availability constraints, we have also considered a limited set of health inputs and non-discretionary variables as explanatory of the differences in efficiency across districts. Moreover, in our comparison of relative efficiency across districts, we did not fully account for important structural and organizational factors such as leadership and governance that play a key role as determinants of performance [10,24–26]. These limitations call for an in-depth assessment that will seek to further explain the observed differences in performance across districts in Zambia.

The DEA approach implemented in the present study is also not without limitations, with the major drawback being the sensitivity of derived estimates to methods and the presence of outliers in the data. Although these issues cannot be circumvented altogether, we have examined the sensitivity of derived estimates using both internal and external consistency checks on the data. Specifically, we fitted 72 separate DEA models, each of which had one less observation obtained by removing one district from our analysis, and then compared the root-mean-square error (RMSE) and pairwise correlations of efficiency score across these models. We have also re-estimated technical efficiency scores using a parametric approach following the stochastic frontier model and compared the outcome with our original DEA-based model. These results (not shown here) confirmed that our efficiency estimates are unlikely to have been biased by outliers, as the RMSE for the different models is less than 2% in most cases, while the pairwise correlation coefficients estimated using alternative models showed a strong significant correlation.

Conclusion

The WHO underscores efficiency in health service delivery as a key attribute of a performance-oriented health system [2,10,24,25]. Therefore, with many health systems facing resource constraints, decision-makers must strive to understand the factors that drive health system performance and seek ways to improve efficiency. Paying attention to factors such as stewardship, resource allocation and management is particularly useful if meaningful progress towards universal health coverage is to be realised in low- and middle income countries.

Competing Interests

All the authors declare that they have no competing interests

Authors' contributions

TA conceptualized the study and extracted all the relevant data. TA and YK developed model, carried out the analyses and drafted the report. FM, AL, HL and AH critically read the draft and provided comments towards the final manuscript. All the authors read and approved the final manuscript.

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Data Sharing

The main data-sets supporting the conclusions of this article are available upon request and with written permission from the Ministry of Health of the Government Republic of Zambia.

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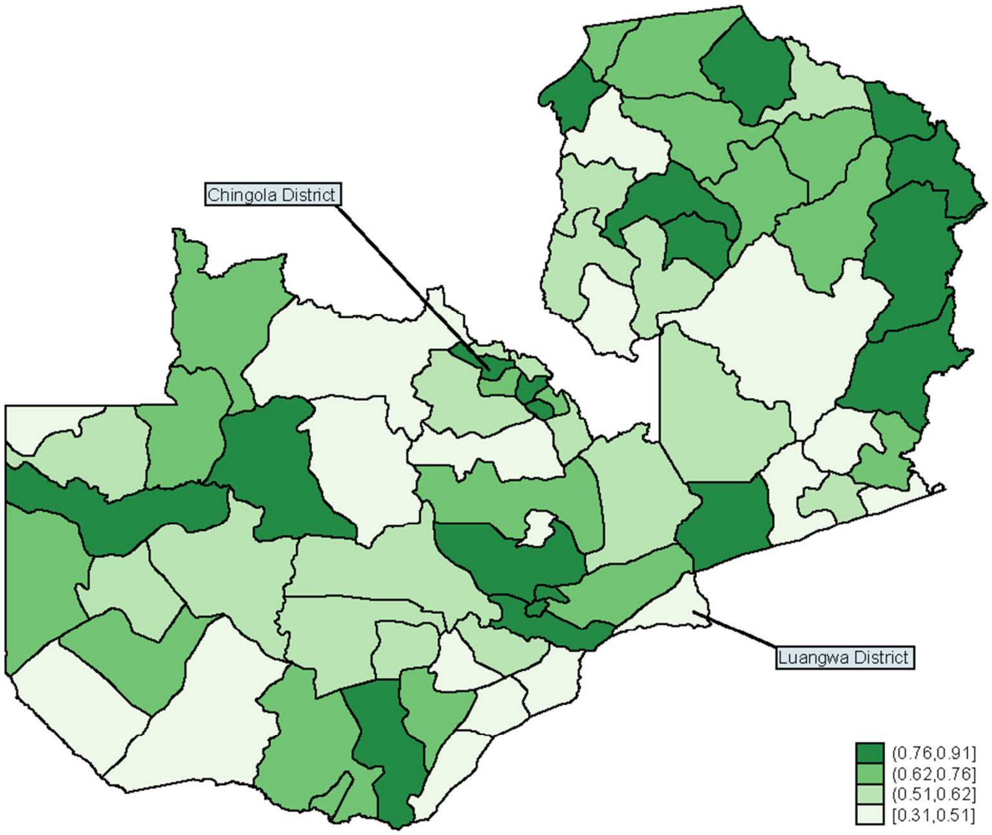

Figure 1: Overall efficiency scores across districts, Zambia
Figure 1
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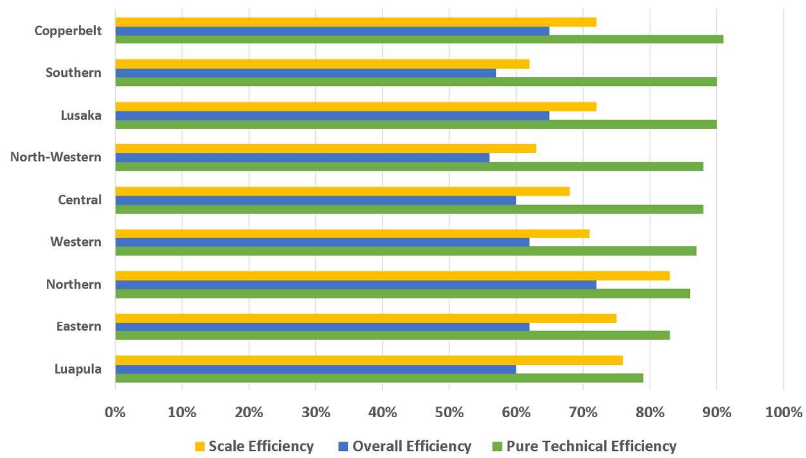

Figure 2: Provincial efficiency ranking, Zambia
Figure 2
338x190mm (200 x 200 DPI)

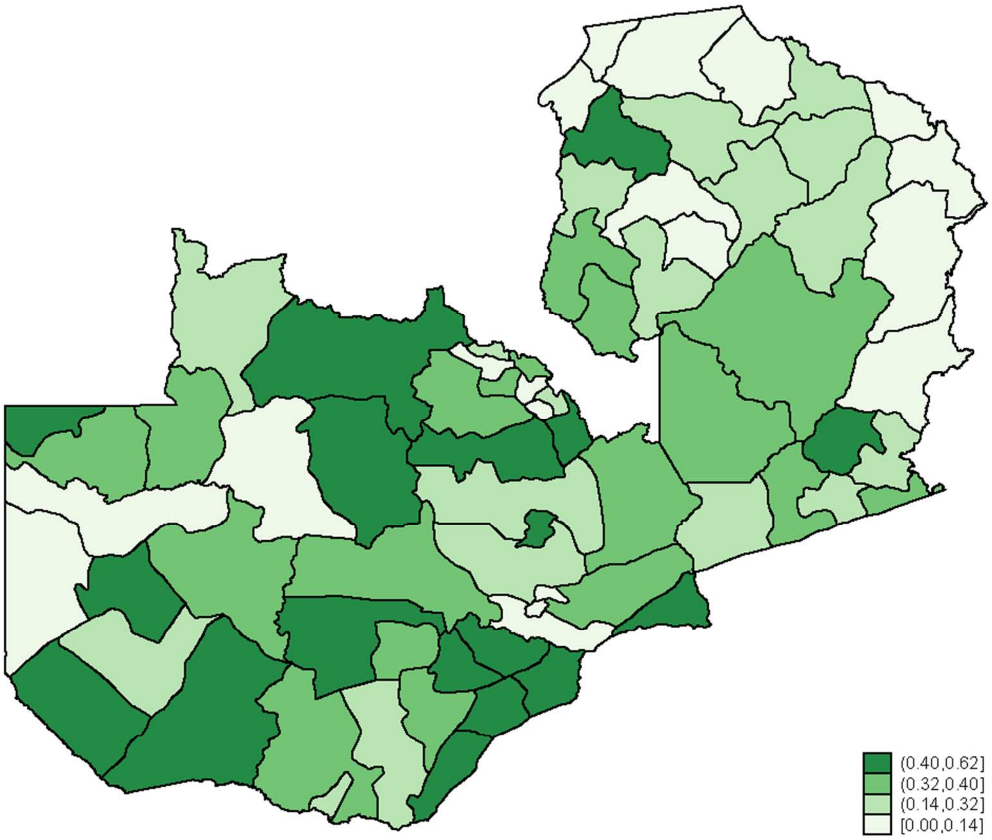

Figure 3: Scale inefficiency across districts, Zambia
Figure 3
120x101mm (200 x 200 DPI)

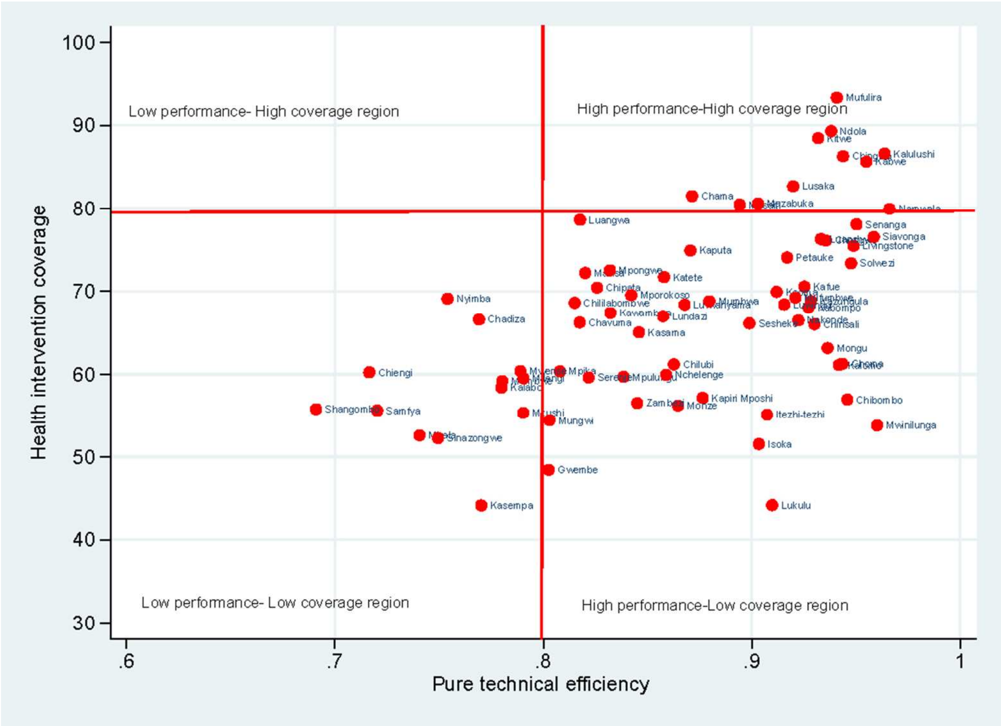

Figure 4: Pure technical efficiency and health intervention coverage in Zambia
Figure 4
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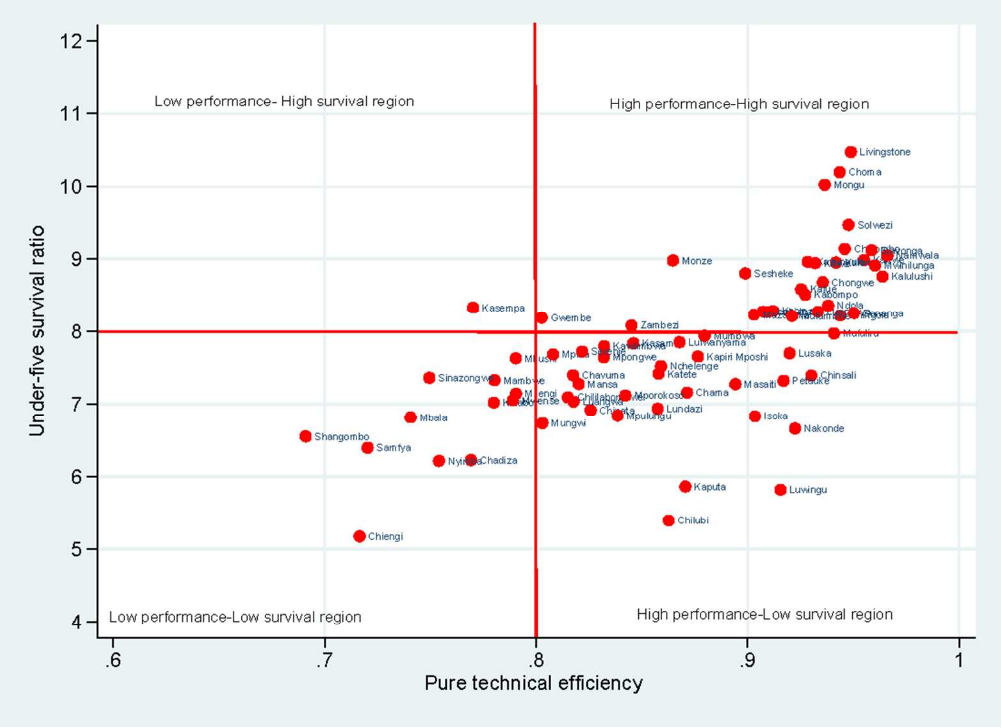

Pure technical efficiency and under-five survival in Zambia

Figure 5

139x101mm (200 x 200 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract This has been included in the main article. See pages 1 and 2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found This has been included – see page 2 of the main article
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported This is included in page 3 of the main article
Objectives	3	State specific objectives, including any pre-specified hypotheses Aspects of this are included in page 3, paragraph 5 of the main article
Methods		
Study design	4	Present key elements of study design early in the paper In pages 4 and 5 of the main article we have introduced data envelopment analysis –as the main method used in our analysis
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Aspects of the study setting have been included in pages 3-(introduction), and 6 (data sources and ethical approval)of the main article
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up N/A *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls N/A *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants The study employs cross-sectional data on health system outputs, inputs and outcomes collected from secondary sources. There were no participants to this study as the analysis is focused at a district level and uses aggregate data.
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed N/A *Case-control study*—For matched studies, give matching criteria and the number of controls per case N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable This is covered in page 6, where we identify main variables used in the analysis as well as define our data sources in detail.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group

		Defined in page 6 of the main article
Bias	9	Describe any efforts to address potential sources of bias In our methodology – we have adopted a data envelopment analysis framework that propagates uncertainty in the estimation. The efficiency scores presented have confidence intervals estimated from 1000 sample draws from the data used in the analysis
Study size	10	Explain how the study size was arrived at Ours is a nationwide study and covers all districts in the country.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why This was a quantitative study based on secondary data analysis. More details available in the methodology section, pages 4 and 5
Statistical methods	12	*(a)* Describe all statistical methods, including those used to control for confounding Explained in the methods section – page 4 and 5
		(b) Describe any methods used to examine subgroups and interactions We have estimated differences in efficiency between provinces and between districts (within provinces) and obtained confidence intervals to test if the differences were statistically significant or not.
		(c) Explain how missing data were addressed The data used for analysis were balanced. We didn't have missing data.
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(d) Describe any sensitivity analyses See page 15in the discussion section. We have conducted bootstrap type sampling approach to test sensitivity.

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed As stated earlier the study does not involve individuals; it is based on district level data.
		(b) Give reasons for non-participation at each stage N/A
		(c) Consider use of a flow diagram N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders- Aspects of this have been defined in page 6, Data sources
		(b) Indicate number of participants with missing data for each variable of interest N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure N/A
		Cross-sectional study—Report numbers of outcome events or summary measures This has been included in the results section- pages 7-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included: Our key results are presented with confidence intervals; see the results section, pages 7-12.
		(*b*) Report category boundaries when continuous variables were categorized N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period. NA. Our analysis is focused on estimating efficiency level, and these are by definition reported in terms of proportions.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Defined in the methods section- see pages 7-12
Discussion		
Key results	18	Summarise key results with reference to study objectives Elaborated in the discussion section – page 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Limitations of the study – clearly included in pages – 1 and 15 of the main article. The methods section also expounds on the limitations of Data Envelopment Analysis
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence See the discussion section- page 13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results The findings of this study are generalizable to other low and middle income countries. This has been included in the results, discussion and conclusion sections of the main article
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based N/A

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Technical and scale efficiency in the delivery of child health services in Zambia: Results from data envelopment analysis

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Short Title:

Technical and scale efficiency in Zambia

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10th July 2016

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Abstract

Objective: Despite tremendous efforts in scaling-up key maternal and child health interventions in Zambia, progress has not been uniform across the country. This raises fundamental health system performance questions that require further investigation. Our study investigates technical and scale efficiency in the delivery of maternal and child health services in the country.

Setting: The study focused on all the 72 health districts of Zambia.

Methods: We compiled a district level database comprising of a health outcome (measured by probability of survival to age 5 years), a health output (measured by coverage of key health interventions) and a set of health system inputs namely, financial resources and human resources for health for the year 2010. We used data envelopment analysis to assess the performance of sub-national units across Zambia with respect to technical and scale efficiency, controlling for environmental factors that are beyond the control of health system decision makers.

Results: Nationally, average technical efficiency with respect to improving child survival was 61.5% (95%CI, 58.2-64.8), which suggests huge inefficiency in resource use in the country, but also the potential for expanding services without injecting additional resources to the system. Districts that were more urbanised and had a higher proportion of educated women were more technically efficient. Donor funding had an insignificant effect on efficiency while the use of improved cooking methods had a positive effect.

Conclusion: With the pressing need to accelerate progress in population health, decision makers must seek efficient ways of delivering services to attain universal health coverage. Understanding the factors that drive performance and seeking ways to enhance efficiency offer a practical pathway through which low-income countries could make progress on population health without necessarily seeking additional resources.

Key words: Technical Efficiency; Scale Efficiency; Data Envelopment Analysis; Health Systems Performance

Strengths and Limitations of Study

- The study measures technical and scale efficiency at the district level, lowest health system management unit in most developing countries
- Data envelopment analysis is used to determine sources of inefficiency in the health system
- The study covers only maternal and child health despite the fact that the health system also encompasses other broader programmatic areas

Introduction

Decentralization of health services has been pivotal in the efforts toward universal health coverage across the developing world [1–3]. There are many drivers of this trend, but improvements in service delivery remains an implicit motivation behind most decentralization efforts [2, 3]. This is mainly anchored around the ideals and principles of local ownership and accountability in service delivery as well as meeting key health system goals with respect to equity, efficiency and responsiveness [1-4].

As in most other countries, Zambia has embraced a decentralized health system model since 1992 as a pathway towards equitable access to health services for its population [3,4]. This entailed devolution of key decision-making and implementation functions to the provincial and district level, where stewards were assigned specific roles aimed at meeting national health policy objectives. Consequently, health resources were directed toward districts which were given primary responsibility in the delivery of key health services to meet various local population health needs [3,5–7].

In this arrangement, the central government is largely focused on setting national priorities and allocating health resources to subnational units, based on projected health needs. In practice, this involves the Ministry of Health (MOH) providing budget ceilings to all district health offices (DHO), which would then make their own plans and budget for their activities in line with local projected health needs, bearing in mind the budget ceiling [3, 5]. Meanwhile, donor organizations, largely channel their funding through non-governmental and faith-based organizations involved in health service provision at the district level [4, 6, 8]. The Provincial Health Offices occupy an intermediate position between the national and district levels mainly taking an oversight role for districts nested within their respective jurisdictions [3,5,6]. The organization of the health system is aimed at ensuring equity in health service delivery, core health objective of the Government of Zambia [5–8].

Despite these efforts, in-depth investigation of the country's health system performance reveals wide subnational heterogeneity in goal attainment. Invariably, this underscores the need to understand the root cause of the differentials in performance across subsystems so that lessons drawn from high performing sub-units could be informative to those that are lagging behind [3,4,7–9]. A systematic and objective comparison of goal attainment and resource allocation across health sub-units in Zambia is timely. The results could provide a valuable benchmarking framework in the effort to push the country's health systems towards better performance [4,9,10].

In this paper we make a systematic comparison in performance across districts and provinces in Zambia; paying attention to the priority area of child survival, as a key health system outcome.

Health intervention coverage for maternal and child health services is considered as the measure of health system output while human and financial resources allocated to districts, are considered as the health system inputs. Further, we seek to demonstrate how data envelopment analysis (DEA) [11] can be applied for efficiency benchmarking and comparative performance assessment for a decentralised health system.

Conceptual Framework

The conceptual framework proposed here borrows its fundamentals from the World Health Organization (WHO) Health System Framework, which effectively connects health inputs, with health outputs, processes and outcomes. [2]. The framework identifies six discrete pillars that need to function in tandem to meet expected health goals [2,4,8–10]. The six pillars of a well-functioning health system include, good health service provision; adequate and progressive health financing; well-functioning human resources; good governance and leadership; a well-functioning health information system; and access to and equitable distribution of essential medicines and health technologies [2].

In our analysis we have focused on human resources and health financing, as the key health systems inputs underlying the production function used in the estimation of efficiency scores. Meanwhile, health intervention coverage is the intermediate health system output through which changes in health outcomes (in this case mortality among children under 5 years of age) are realised. Health intervention coverage was constructed as a composite metric comprising of DPT3 and measles immunizations, skilled birth attendance, and malaria prevention. The approach employed in the construction of this metric and its merits are further discussed in the methods section.

We selected under 5 mortality rate (U5MR) in our assessment of district health system performance, since it is a key indicator used to monitor progress towards reduction in child mortality, which was a key objective of Millennium Development Goals (MDG). This indicator is further recognised as a good measure of overall population health, particularly in developing countries. Meanwhile, our health intervention coverage- as a measure of health system output-comprised of essential maternal and child health interventions critical for child survival in most developing countries in the tropics [4, 8]. However, given the fact that health outcomes depend on a variety of factors, some of which are under the control of the health sector and some that are not, we remain cognizant of the fact that there may not exist a direct relationship between improvement in health system inputs and achievement of better health system output and health outcomes [11]. Another point that equally deserves attention with regard to the study is the fact that efficiency estimates refer to the efficiency of an output (or an outcome) for a given level of input, and does not refer to the level of the output (or outcome) itself. In other words, it is still possible for a district or a country to be fully efficient and yet have lower output and/or outcome levels [12]. We have sought to explore this further in the assessment of district health system performance.

Methods

In the definition of efficiency, a distinction should be made between technical, allocative, and scale efficiency measures [13-15]. In this study only technical and scale efficiencies were considered, mainly because input prices needed for the estimation of cost functions, were not available to us [12, 14]. For estimation of efficiency scores, we employed the Banker, Charnes, and Cooper (BCC) formulation of the DEA model. The choice of the BCC approach is partly guided by the fact that all our variables were ratio-based, and we endeavoured to take economies of scale into account in the analysis. In addition, like all other DEA models, the BCC model also handles multiple inputs and outputs, which is particularly suited for complex fields such as health systems [13,15], where there is a multidimensional mix of input and output variables that have to be considered simultaneously [15-18]. Further, we applied the approach developed by Charnes, Cooper and Rhodes (CCR) to enable us to decompose overall efficiency score into scale and pure technical efficiency.

Given that each decision-making unit (DMU) may face locally unique conditions, the DEA approach assesses each unit separately, assigning some weighted combination of inputs and outputs that maximizes its efficiency score [13,15]. Algebraically, this is achieved by solving for each DMU (district) the following linear programming problem [15].

$$\max_{u,v} \left(\frac{\sum_{o=1}^{o} u_o \times y_{o0}}{\sum_{i=1}^{i} vi \times k_{i0}} \right)$$

$$\text{subject to: } \frac{\sum_{o=1}^{o} u_o \times y_{on}}{\sum_{i=1}^{i} vi \times k_{in}} \leq 1 \quad n = 1, \ldots \ldots N$$

Where

y_{o0} = quantity of output "o" for DMU_0

u_o = weight attached to output o, u_o > 0, o = 1, …….., O

k_{i0} = quantity of input "i" for DMU_0

v_i = weight attached to input i, v_o > 0, i = 1, …….., I

The equation is solved for each DMU iteratively (for n=1, 2,…, N), and therefore the weights that maximize the efficiency of one DMU might differ from the weights that maximize the efficiency of another DMU [17, 18]. Theoretically, these weights can assume any non-negative value, while the resulting technical efficiency scores vary only within a scale of 0 to 1, subject to the constraint that all other DMUs also have efficiencies between 0 and 1.

Technically, a DEA-based efficiency analysis can take either an input- or output-orientation. In an input-orientation, the primary objective is to minimize inputs, while in an output-orientation the goal is to attain the highest possible output with the given amounts of inputs. In our case, an output-oriented DEA model was deemed more appropriate on the premise that district health teams have essentially a fixed set of inputs to work with at any given time [3,5,6]. In other words, the district health system stewards would have more leverage in controlling outputs through innovative programming rather than raising additional resources.

As performance and institutional capacity are expected to vary across districts [4], a variable-returns-to-scale (VRS) approach was also considered more relevant to the study setting. This approach allows for economies and diseconomies of scale, rather than imposing the laws of direct proportionality in input-output relationships as espoused in the constant-returns to scale (CRS) [16-19]. A VRS model also offers the advantage of decomposing Overall Technical Efficiency into Pure Technical Efficiency (PTE) and Scale Efficiency (SE), which is essential in locating the source(s) of differentials in performance across production units [16–18].

Data Sources

We used data from the Malaria Control Policy Assessment project (MCPA) in Zambia, which compiled one of the most comprehensive district-level data on U5MR, health intervention coverage and socioeconomic indices for the country based on standardized population health surveys [4,8]. For both indicators, to capture the most recent period for the country, the data representing the year 2010 were used.

In our DEA model, U5MR was used to measure district health system outcomes. In order to measure the outcome, output and inputs in the same direction in such a way that "more is better" we converted the probability of dying under five years of age (which is conventionally known as under-five mortality rate) into probability of survival to age 5. This was accomplished simply by subtracting the reported under five mortality rate per 1000 live births from a 1000 [11, 20]. Health intervention coverage was a composite metric comprising of the proportion of the population in need of a health intervention who actually receive it [4, 8].

The composite metric comprised of DPT3 and measles immunizations, skilled birth attendance, and malaria prevention. For malaria prevention, we included the indicator approximating malaria prevention efforts across districts, i.e. the combination of insecticide treated net (ITN) ownership or indoor residual spraying (IRS) coverage. The average of all the 5 health interventions for each district, was taken as the health intervention coverage [4]. This innovative way of data reduction through combining a range of health interventions has the advantage of reducing the number of variables that enter into the model. This in turn helps to maintain reasonable balance between the number of DMUs and input and output variables which is required to avoid scarcity of adjacent reference observations or "peers," which if not taken care of would lead to sections of the frontier being unreliably estimated and inappropriately positioned [15, 16,18].

For the inputs part, we obtained a dataset of annual operational funds from both government and donors to each of the 72 districts for the year 2010. These data are available through the Directorate of Health Policy and Planning (DHPP) of the Ministry of Health [8]. Using population data from the Central Statistics Office of Zambia, we calculated the total population-adjusted funds disbursed to each district. We further obtained data from the Ministry of Health on the human resource complement for the year 2010 covering the medical professionals (doctors and clinical officers) and nurses (including midwives) for each district and adjusted them for the district population.

In addition, we included the mean years of education among women aged 15-49 years, the proportion of districts funds originating from donors, household access to electricity and the proportion of household with improved cooking methods, as environmental variables that are external to district health units but nonetheless affect performance and efficiency levels of the health system. These variables were chosen based on their importance in addressing the key global health targets around maternal and child health in Africa [1–3]. Donor funding is a major feature in African health systems and has been a subject of major debate in the efforts toward health system strengthening. Similarly, the relationship between health and education, particularly among women, has been variously documented [2–4,8]. Both datasets were obtained from the MCPA database.

Analyses were done using R version 3.2.1, specifically the r-DEA package that has the capability to combine the inputs, outputs, and environmental variables into one stage of analysis. This package implements a double bootstrap estimation technique to obtain bias-corrected estimates of efficiency measures, adjusting for the unique set of environmental characteristics under which different DMUs are operating [11, 21]. To obtain robust estimates, we bootstrapped the model 1,000 times and generated uncertainty around the estimates [21, 22]. The same approach was used to generate robust DEA efficiency scores corresponding to health intervention coverage, applying the same input and environmental variables.

Ethical approval

Permission to conduct the study was obtained from the Ministry of Health, Zambia. Since our study only used de-identified secondary data, we were granted exemption from the IRB, University of Zambia: IRB00001131 of IROG000074.

Results

Descriptive statistics

Table 1 presents descriptive statistics for the variables used in the study. The range for both inputs and outputs is quite wide. For example, under-five mortality rate across districts varies between 87.16 deaths per 1000 live births and 161.96 deaths per 1000 live births, while health intervention coverage varies from 44.20% to 93.42%. Similar patterns are apparent for health workforce and financing indicators, where the distribution of nursing personnel ranged from 5.16 nurses/1000 population to 33.03 nurses/1000 population, while total funds to districts ranged from 4.24 million ZMK/1000 population to 23.77 million ZMK/1000 population. This suggests that at the subnational level, the Zambian health system is quite heterogeneous.

Table 1: Summary statistics of the variables

	Variable	Units	Mean	Standard deviation	Min	Max
Outcomes	Under-five mortality	*Deaths per 1000 live births*	115.61	(14.66)	(87.16)	(161.96)
	Under 5 Survival Rate	*per 1000 live births*	884.39	(14.73)	(838.04)	(912.84)
Outputs	Health intervention[ii] coverage	*Percentage %*	67.09	(10.99)	(44.20)	(93.42)
Inputs	Total funds	*Millions of Zambian Kwacha per 1,000 population*	13.60	(3.55)	(4.24)	(23.77)
	Medical personnel	*Medical personnel[iii] per 1,000 population*	6.96	(3.34)	(.92)	(18.23)
	Nursing personnel	*Nursing personnel[iv] per 1,000 population*	12.72	(5.76)	(5.16)	(33.03)
Environmental	Proportion of donor funds	*Percentage%*	38.43	(5.21)	(31.39)	(57.21)
	Proportion of households with access to electricity	*Percentage%*	13.23	(17.06)	(0.19)	(61.29)
	Proportion of households with improved cooking	*Percentage %*	10.26	(14.55)	(0.33)	(53.77)
	Average years of education for women aged 15-44	Years	5.72	(1.60)	(2.93)	(9.51)

[ii] Health intervention coverage is a composite metric comprising of 5 health interventions
[iii] Medical personnel includes both medical doctors and clinical officers (medical assistants).
[iv] Nursing personnel includes both registered nurses and midwives

Table 2, makes provincial comparisons for input, output and outcome variables, revealing further heterogeneity across the country. For instance, in the predominantly urbanized Copperbelt province, health intervention coverage was as high as 81.05% (95%CI: 75.31-86.78), in comparison to the North-Western province, which was predominantly rural, with a coverage of 61.64% (95%CI: 53.80-69.48). Still within provinces, there was significant heterogeneity, considering that all provincial estimates for health intervention coverage had wide confidence intervals of more than 10% points. This trend further underscores the differences in goal attainment across the districts in country. Similar differences were also observed with respect to under-five survival rate where provincial estimates revealed a wide gap across provinces, with the Southern province topping the list with 898.14 survivors per 1000 live births (95%CI: 892.64-903.63) and Northern province lagging with 869.82 survivors/1000 live births (95%CI: 862.25-877.38).

Table 2: Summary of variables across provinces

Provinces	Under-five mortality	Under-five survival	Health intervention coverage	Total funds	Medical personnel	Nursing personnel	Districts
Units	*Deaths per 1000 live births*	*Per 1000 live births*	*Percentage%*	*Millions of Zambian Kwacha per 1,000 population*	*Medical Personnel per 1,000 population*	*Nursing Personnel per 1,000 population*	*Number*
Central	109.46 (103.00, 115.91)	890.54 (884.09, 897.00)	63.92 (54.41, 73.42)	12.70 (11.97, 13.44)	7.75 (5.63, 9.87)	12.02 (6.53, 17.51)	(6)
Copperbelt	111.07 (106.40, 115.75)	888.93 (884.25, 893.6)	81.05 (75.31, 86.78)	10.27 (7.39, 13.16)	8.08 (6.36, 9.80)	16.83 (14.89, 18.77)	(10)
Eastern	126.35 (120.73, 131.97)	873.65 (868.03, 879.27)	69.96 (65.41, 74.50)	14.58 (12.71, 16.46)	6.64 (4.26, 9.02)	10.26 (8.26, 12.27)	(8)
Luapula	127.99 (115.62, 140.36)	872.01 (859.64, 884.38)	62.18 (57.94, 66.43)	15.26 (13.94, 16.57)	5.99 (4.44, 7.54)	10.11 (7.35, 12.88)	(7)
Lusaka	111.76 (101.84, 121.69)	888.24 (878.31, 898.16)	77.00 (71.96, 82.05)	11.26 (2.56, 19.96)	7.65 (4.36, 10.94)	15.59 (3.60, 27.58)	(4)
North-Western	106.64 (101.07, 112.22)	893.36 (887.78, 898.93)	61.64 (53.80, 69.48)	16.52 (14.59, 18.45)	6.89 (3.77, 10.00)	15.98 (10.65, 21.32)	(7)
Northern	130.18 (122.62, 137.75)	869.82 (862.25, 877.38)	62.52 (58.38, 66.67)	13.76 (12.57, 14.96)	3.66 (2.40, 4.93)	8.82 (6.72, 10.93)	(12)
Southern	101.86 (96.37, 107.36)	898.14 (892.64, 903.63)	65.08 (58.06, 72.10)	12.79 (11.49, 14.10)	9.27 (7.05, 11.50)	14.80 (11.66, 17.94)	(11)
Western	110.49 (99.99, 120.99)	889.51 (879.01, 900.01)	62.24 (54.07, 70.42)	15.73 (14.67, 16.79)	7.73 (5.70, 9.77)	11.40 (7.80, 15.01)	(7)

95% confidence intervals in parentheses

Overall efficiency, pure technical efficiency, and scale efficiency

Figure 1, shows the estimates of overall technical efficiency (OTE) scores obtained using an output-oriented bias-corrected DEA model across the 72 districts of Zambia considering under-five survival rate as our outcome indicator. A value of 1 indicates that a district produces at the frontier; and the lower the value, the farther the district is from the efficient frontier. As with the input, output and outcome indicators shown in Table 1, the results shown in Figure 1 portray a deeply heterogeneous picture in terms of overall technical efficiency across subnational units. For example, both the worst and best performing districts, Luangwa, at 31.0% (95%CI: 29.5-33.0) and Kafue at 88 %(95%CI: 79.2-97.1) are both found in the predominantly urban province of Lusaka.

Only 22 (31.0 %) districts in the country (predominantly from the Northern and Lusaka provinces) had efficiency scores above 70%. The next tier of top performers, with an overall technical efficiency score between 60% and 70%, showed a mixed picture but also with predominant representation from the Copperbelt province and other districts from the northern and eastern parts of the country, which suggests a phenomenon of spatial clustering in performance in the country. The average efficiency score for the country as a whole was 61.5% (95%CI, 58.2-64.8), which suggests a significant potential for further improvement without the need for additional resources.

Figure 2 shows that there was a strong association between overall technical efficiency scores for under-five survival (outcome) and the overall technical efficiency scores for health intervention coverage (output). This means that efficient attainment of health intervention coverage is strongly predictive of how efficiently districts in Zambia perform in meeting their child survival objectives. However, in as much as this is prevailing in most districts, there are some that deviate from this trend raising further questions into the role of environmental factors that are beyond the health system.

The OTE, can be further decomposed into pure technical efficiency (PTE) which is a measure of managerial performance in the production process and scale efficiency (SE) which is the ability to choose the optimum size of resources in production. Figure 3 shows PTE, SE, and OTE scores for the nine provinces of Zambia. OTE appears to be higher in the Northern, Lusaka and Eastern provinces. Still Northern and Lusaka provinces are also in the lead in terms of PTE, while the Southern and North-Western provinces are at the bottom tier. Meanwhile, SE appears to be generally high across the country with the Lusaka province leading at 100%.

The efficiency measures discussed above only look into the use of resources or scale of operation and do not directly address outcomes. For instance, it is possible for districts or provinces to have lower service coverage but perform better in the management of resources available to them and vice versa. Figure 4 shows a comparison of PTE and health intervention coverage across the 72 districts of Zambia, with the quadrants defined at the means of each estimate. The PTE scores presented in the figure provide opportunity for policymakers and local decision-makers to examine the effect of managerial competence without the diluting effects of scale of operation on performance.

In Figure 4, 37 of the 72 districts fall into the high managerial performance category, of which 18 have managed to combine high managerial efficiency with high health intervention coverage. However, in the remaining 19 districts in this category, health intervention coverage is still low despite high efficiency. On the other hand, there are 17 districts, where both managerial performance and coverage remain low. The average pure technical efficiency score was 66.3% (95%CI: 62.9-69.7), while actual scores ranged between 31.3% (95% CI: 31.0-32.9) and 89.5% (95%CI: 83.7-96.8).

Further, figure 5 shows a comparison between under-five survival across districts and PTE. It is clear that high performance in terms of PTE in a given district does not necessarily translate to better health outcomes. This is observed in districts such as Chiengi and Chilubi which score highly in terms of PTE but trail their peers in under- five survival.

Effects of environmental factors on overall technical efficiency

Table 3, presents results from regression analysis to estimate the effect of environmental factors on the OTE for under five survival at the district level. The results were obtained using the bias-corrected two-stage estimation process for the four environmental variables we chose for our analysis. The results suggest that the channelling of donor funding in Zambia seems to have an insignificant effect on technical efficiency. Meanwhile, female education had a significant positive effect, confirming the interdependencies between health and education noted in previous studies.

Table 3: The effects of the environmental variables

	Coefficients
Constant	0.85*
Female education	0.18**
Household access to electricity	-0.03
Proportion of funding from donor sources	-0.09
Household access to improved cooking	0.02

$^{*}p < 0.05$, $^{**}p < 0.01$

Discussion

With the push toward universal coverage across the developing world and uncertainties about future global investment on health, the question of efficiency in health service delivery has become increasingly important. This paper attempted to evaluate the extent of pure technical, scale, and overall technical efficiencies in Zambia using cross-sectional data from 72 districts. In addition, an attempt has been made to investigate the role of environmental factors specifically donor funds and maternal education on the efficiency of maternal and child health in the country. This is particularly relevant given the finite nature of available health resources in the face of rising health needs [1,2,4,8].

DEA is an attention-directing managerial technique [15-19, 23]. By evaluating the relative efficiency of sub-national units, it locates trouble spots in the service delivery system and potential for further improvement. This is based on the understanding that in a decentralized health system, subnational units have a far-reaching impact on the overall performance of the health system [4,7,9]. Through this framework, policymakers can objectively benchmark the performance of the district health system with the aim of fostering peer learning and accountability.

DEA has been extensively used to assess the performance of health systems across different settings. For instance, Ortega, Sanjuan and Casquero [11] used DEA to analyse the impact of income inequality and government effectiveness on the efficiency of health inputs to improve child survival in developing countries. Kirigia, Sambo and Lambo [24] applied DEA to measure technical and scale efficiency across 55 public hospitals in South Africa. Kirigia, Emrouznejad and Sambo [25] also used the DEA methodology to measure relative efficiency of 54 hospitals in Kenya. In Ghana, Alhassan et al. [14], applied DEA to estimate technical efficiency of private and public health facilities accredited by the National Health Insurance Authority. In addition, Masiye F. [26] has used DEA to measure technical and scale efficiency of hospitals in Zambia.

Building on existing evidence on application of DEA in Zambia, findings from the present study reveal significant heterogeneity in performance across the country. It is clear that overall technical efficiency in the production of health outcomes is strongly correlated with the efficiency in the production of health outputs, considering the same inputs. However, as pointed out earlier efficiency estimates refer to the efficiency of an output (or an outcome) for a given level of input, and does not refer to the level of the output (or outcome) itself. In other words, it is still possible for a district or a country to be fully efficient and yet have lower output and/or outcome levels [11, 12].

Low performance in districts and provinces was largely due to both poor input utilization (i.e., pure technical inefficiency) rather than the failure to operate at the most productive scale size (i.e., scale inefficiency). The average PTE score for the country has been observed to be 66.3%, which implies that 33.7% percentage points of the about 38.5% overall technical inefficiency in the country was due to district health managers who are not following appropriate management practices and are selecting incorrect input combinations. The remaining shortfall in overall inefficiency appears to be due to inappropriate scale of operations. This is consistent with the findings of Masiye F. [26], which established that a significant proportion of hospitals in Zambia were technically inefficient.

Specifically, urban districts seemed to be more scale-efficient in comparison to their rural counterparts, probably as a result of having a densely populated environment where the marginal cost of increasing population coverage is significantly lower than in rural areas. Similarly, urban residents tend to have better access to health services, both in physical and financial terms, than their rural counterparts, resulting in higher utilization of the available services. In contrast, due to access challenges in rural areas, there is often low utilization of the available health services.

We showed that 37 of the 72 districts fall into the high managerial performance category, of which 18 have managed to combine high managerial efficiency with high health intervention coverage. In the remaining 19 of the 37 districts in this category, health intervention coverage is still low, but this had nothing to do with the efficiency with which managers combined the inputs at their disposal, suggesting that for this group of districts the only way to improve coverage could be to put additional resources into the system. On the other hand, in the remaining 17 districts, where both PTE and coverage of services remained low, improvements in health intervention coverage should first and foremost focus on improving managerial underperformance (i.e., managerial inefficiency) in organizing the inputs at their disposal, followed by introducing new resources, especially in areas where coverage rates are extremely low. A similar interpretation applies when considering health outcomes whereby in those districts such as Chiengi and Chilubi where efficiency level is already high but outcome levels are still low, further progress in child survival can only come by way of putting new resources in these areas.

We further demonstrated that the relationship between health system inputs, outputs and outcomes is complex [11]. In as much as there is a strong association between the efficiency measures in the production of health outputs and health outcomes, there is some deviations that need further investigation. Health systems are mostly responsible for organizing the available resources to maximize health outputs with the hope that these would translate into better health outcomes. However, environmental factors within which the district health system is operating also play a significant role in determining outcomes.

Therefore, in health programming it is equally important not to ignore the social determinants of health, particularly the educational status of women, which is shown to have a positive impact on the efficiency of the health care system. Educated women are likely to be aware of and demand appropriate health services when they need them. In fact, the variables that have been included in the composite metric, comprise of skilled birth attendance, childhood immunizations and malaria prevention, all that are considered crucial for maternal and child health in most of Africa [4]. Therefore, it would only be natural that educated women would have the awareness to seek and utilize these important health services when they are available, in comparison to their less educated counterparts. The cumulative effect at the district level would also translate to higher utilization and therefore efficient service provision in districts where women are more educated. This would ultimately translate to better survival in areas where care-givers are better educated.

In as much as donor funding has been a dominant feature of the African health systems landscape in recent years and has contributed significantly to the scale-up of priority health interventions, many have raised questions in terms of its effectiveness [2,27–29]. From this analysis we cast doubt as to whether the donor funds are being channelled and utilized optimally at the district level. There are multiple pathways through which donor funds could adversely affect efficiency at the district level. First, districts with limited institutional capacity might lack the implementation capacity to use the available funds to deliver the required health services effectively. This would lead to inefficiency within the health system, whereby districts will have large amounts of money without the ability to deliver required services. Second, donor funds are often earmarked for specific programs such as malaria, HIV/AIDS, and tuberculosis [3]. In such vertical programming, the donor-funded programs might reduce other health programs' implementation capacity, leading to sub-optimal performance in other key program areas such as skilled birth attendance and other preventive services that are relevant for maternal and child health care.

Our analysis is not, however, without limitations. First, we have only focused on a limited number of health system outputs (i.e., maternal and child health indicators), despite the fact that a health system produces many more outputs covering different programmatic areas. Similarly, due to data availability constraints, we have also considered a limited set of health inputs and non-discretionary variables as explanatory of the differences in efficiency across districts. Moreover, in our comparison of relative efficiency across districts, we did not fully account for important structural and organizational factors such as leadership and governance that play a key role as determinants of performance [10,27–29]. These limitations call for an in-depth assessment that will seek to further explain the observed differences in performance across districts in Zambia.

The DEA approach implemented in the present study is also not without limitations, with the major drawback being the sensitivity of derived estimates to methods and the presence of outliers in the data. Although these issues cannot be circumvented altogether, we have examined the sensitivity of derived estimates using both internal and external consistency checks on the data. Specifically, we fitted 72 separate DEA models, each of which had one less observation obtained by removing one district from our analysis, and then compared the root-mean-square error (RMSE) and pairwise correlations of efficiency score across these models. We have also re-estimated technical efficiency scores using a parametric approach following the stochastic frontier model and compared the outcome with our original DEA-based model. These results (not shown here) confirmed that our efficiency estimates are unlikely to have been biased by outliers, as the RMSE for the different models is less than 2% in most cases, while the pairwise correlation coefficients estimated using alternative models showed a strong significant correlation.

Conclusion

The WHO underscores efficiency in health service delivery as a key attribute of a performance-oriented health system [2,10,26,27]. Therefore, with many health systems facing resource constraints, decision-makers must strive to understand the factors that drive health system performance and seek ways to improve efficiency. Paying attention to factors such as stewardship, resource allocation and management is particularly useful if meaningful progress towards universal health coverage is to be realised in low- and middle income countries.

Competing Interests

All the authors declare that they have no competing interests

Authors' contributions

TA conceptualized the study and extracted all the relevant data. TA and YK developed model, carried out the analyses and drafted the report. FM, AL, HL and AH critically read the draft and provided comments towards the final manuscript. All the authors read and approved the final manuscript.

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Data Sharing

The main data-sets supporting the conclusions of this article are available upon request and with written permission from the Ministry of Health of the Government Republic of Zambia.

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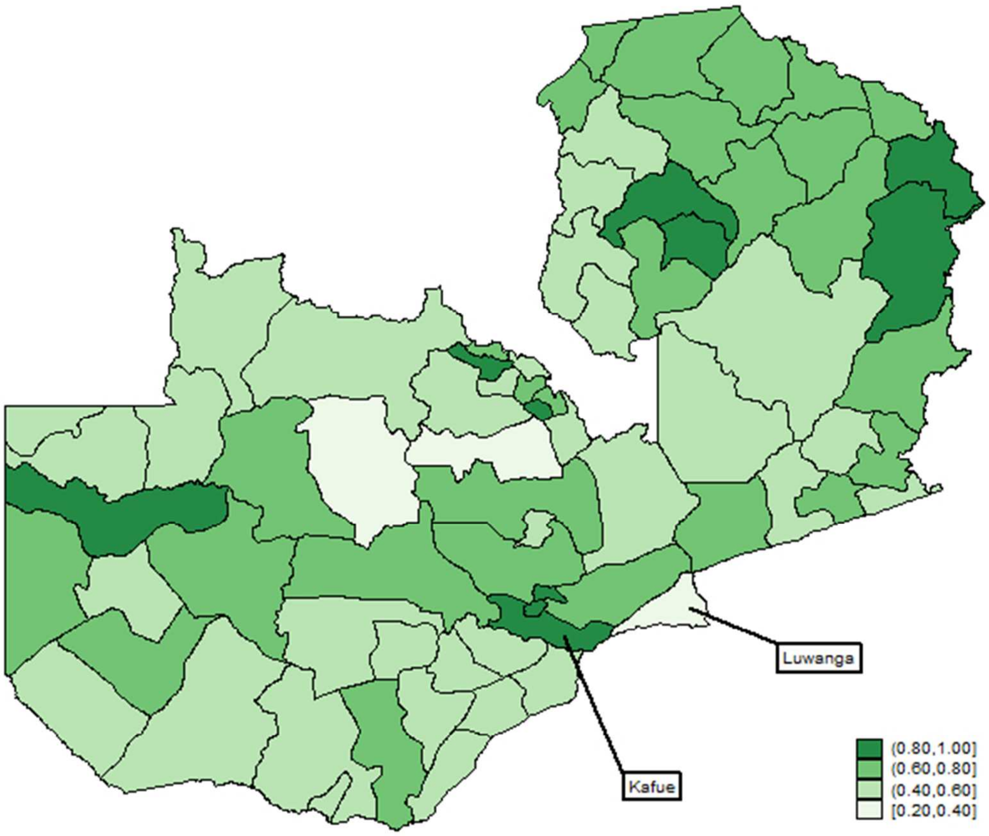
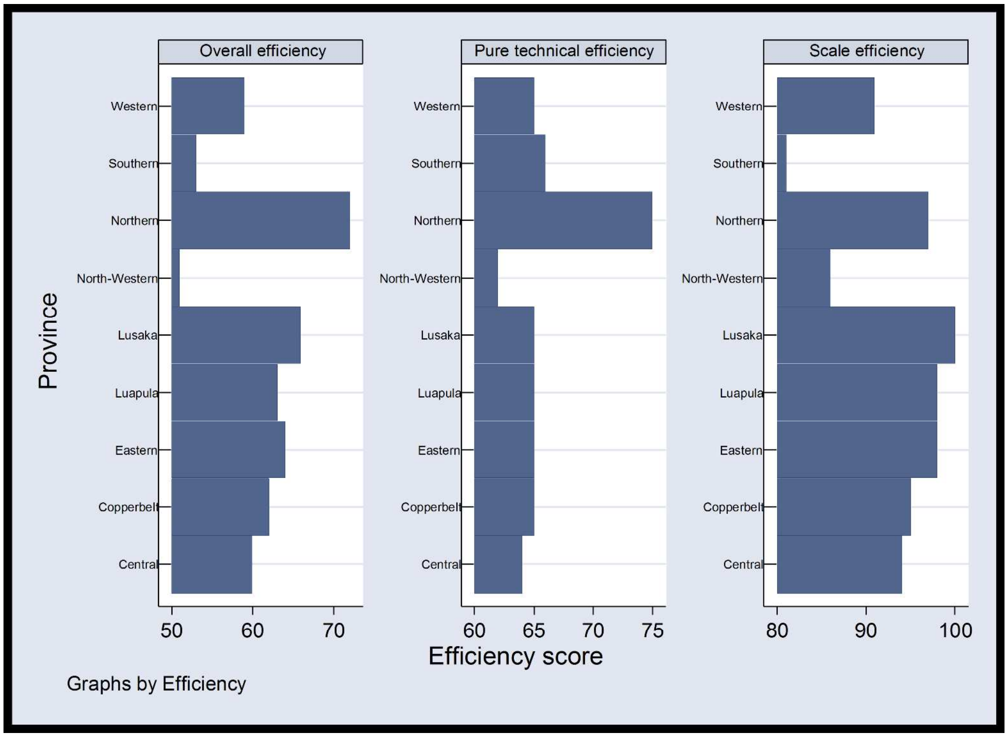
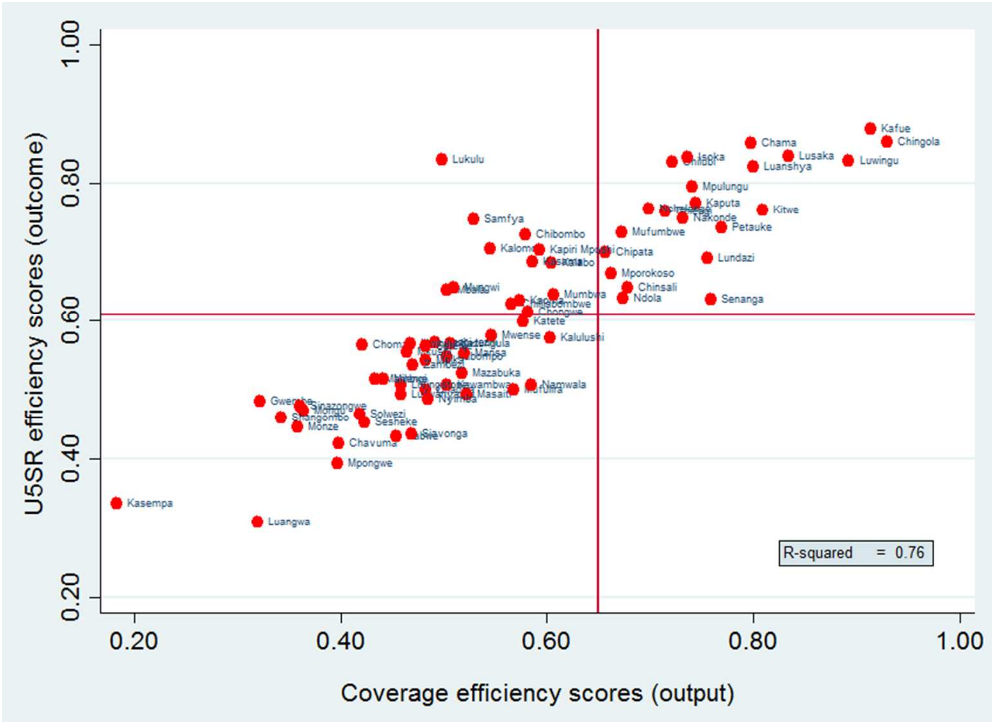


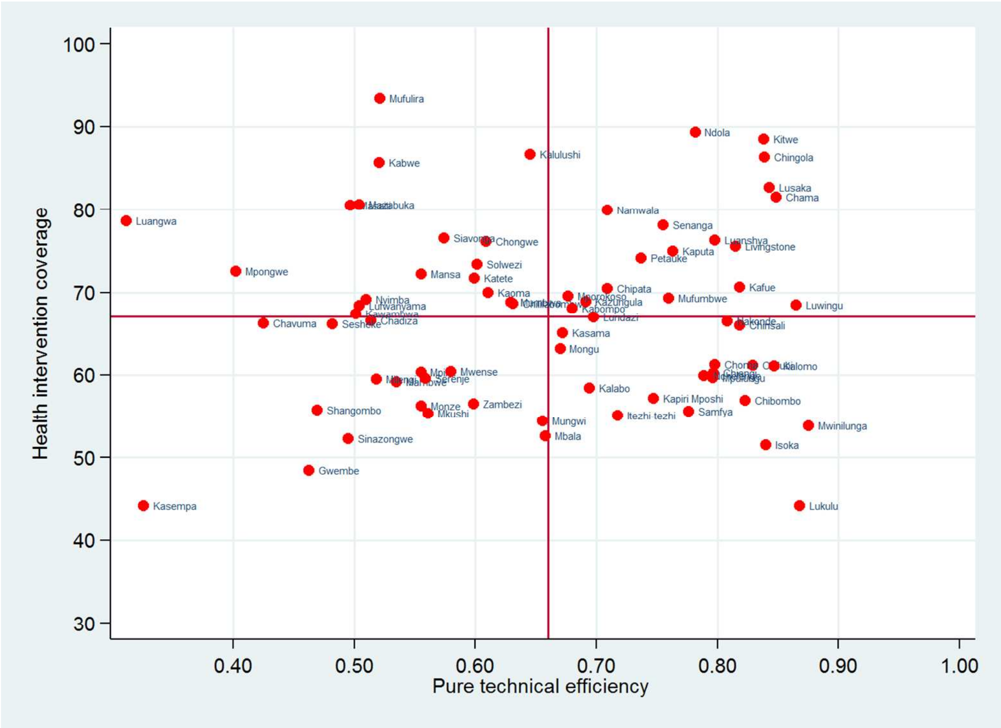
Overall technical efficiency scores across districts in Zambia
Figure 1
50x42mm (300 x 300 DPI)



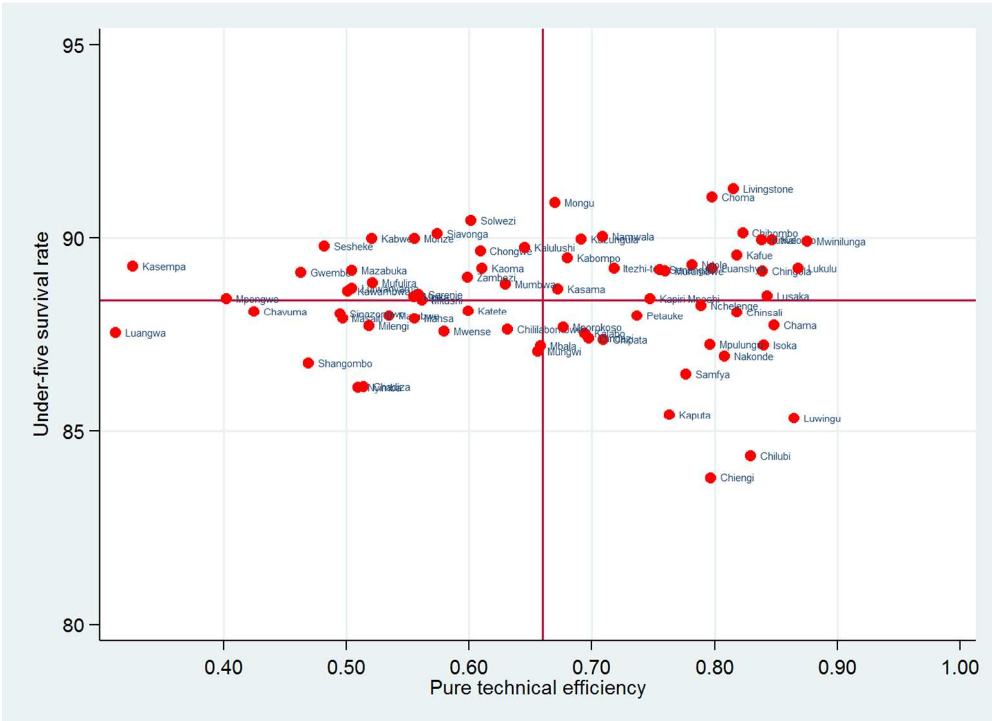
Provincial efficiency ranking across Zambia
Figure 2
284x207mm (300 x 300 DPI)



A comparison of under-5 survival and health intervention coverage technical efficiency scores
Figure 3
72x52mm (300 x 300 DPI)



A comparison of pure technical efficiency and health intervention coverage in Zambia
Figure 4
122x89mm (300 x 300 DPI)



A comparison pure technical efficiency and under-5 survival in Zambia
Figure 5
122x89mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract This has been included in the main article. See pages 1 and 2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found This has been included – see page 2 of the main article
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported This is included in page 3 of the main article
Objectives	3	State specific objectives, including any pre-specified hypotheses Aspects of this are included in page 3, paragraph 5 of the main article
Methods		
Study design	4	Present key elements of study design early in the paper In pages 4 and 5 of the main article we have introduced data envelopment analysis –as the main method used in our analysis
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Aspects of the study setting have been included in pages 3-(introduction), and 6 (data sources and ethical approval)of the main article
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up N/A *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls N/A *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants The study employs cross-sectional data on health system outputs, inputs and outcomes collected from secondary sources. There were no participants to this study as the analysis is focused at a district level and uses aggregate data.
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed N/A *Case-control study*—For matched studies, give matching criteria and the number of controls per case N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable This is covered in page 6, where we identify main variables used in the analysis as well as define our data sources in detail.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group

		Defined in page 6 of the main article
Bias	9	Describe any efforts to address potential sources of bias In our methodology – we have adopted a data envelopment analysis framework that propagates uncertainty in the estimation. The efficiency scores presented have confidence intervals estimated from 1000 sample draws from the data used in the analysis
Study size	10	Explain how the study size was arrived at Ours is a nationwide study and covers all districts in the country.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why This was a quantitative study based on secondary data analysis. More details available in the methodology section, pages 4 and 5
Statistical methods	12	*(a)* Describe all statistical methods, including those used to control for confounding Explained in the methods section – page 4 and 5
		(b) Describe any methods used to examine subgroups and interactions We have estimated differences in efficiency between provinces and between districts (within provinces) and obtained confidence intervals to test if the differences were statistically significant or not.
		(c) Explain how missing data were addressed The data used for analysis were balanced. We didn't have missing data.
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(d) Describe any sensitivity analyses See page 15in the discussion section. We have conducted bootstrap type sampling approach to test sensitivity.

Continued on next page

Section	Item	Recommendation
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed As stated earlier the study does not involve individuals; it is based on district level data.
		(b) Give reasons for non-participation at each stage N/A
		(c) Consider use of a flow diagram N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders- Aspects of this have been defined in page 6, Data sources
		(b) Indicate number of participants with missing data for each variable of interest N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure N/A
		Cross-sectional study—Report numbers of outcome events or summary measures This has been included in the results section- pages 7-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included: Our key results are presented with confidence intervals; see the results section, pages 7-12.
		(*b*) Report category boundaries when continuous variables were categorized N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period. NA. Our analysis is focused on estimating efficiency level, and these are by definition reported in terms of proportions.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Defined in the methods section- see pages 7-12
Discussion		
Key results	18	Summarise key results with reference to study objectives Elaborated in the discussion section – page 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Limitations of the study – clearly included in pages – 1 and 15 of the main article. The methods section also expounds on the limitations of Data Envelopment Analysis
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence See the discussion section- page 13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results The findings of this study are generalizable to other low and middle income countries. This has been included in the results, discussion and conclusion sections of the main article
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based N/A

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Technical and scale efficiency in the delivery of child health services in Zambia: Results from data envelopment analysis

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Technical and scale efficiency in the delivery of child health services in Zambia: Results from data envelopment analysis

Short Title:

Technical and scale efficiency in Zambia

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Abstract

Objective: Despite tremendous efforts to scale up key maternal and child health interventions in Zambia, progress has not been uniform across the country. This raises fundamental health system performance questions that require further investigation. Our study investigates technical and scale efficiency in the delivery of maternal and child health services in the country.

Setting: The study focused on all 72 health districts of Zambia.

Methods: We compiled a district-level database comprising health outcomes (measured by the probability of survival to 5 years of age), health outputs (measured by coverage of key health interventions) and a set of health system inputs, namely, financial resources and human resources for health, for the year 2010. We used data envelopment analysis to assess the performance of subnational units across Zambia with respect to technical and scale efficiency, controlling for environmental factors that are beyond the control of health system decision makers.

Results: Nationally, average technical efficiency with respect to improving child survival was 61.5% (95%CI: 58.2-64.8), which suggests that there is not only a huge inefficiency in resource use in the country but also the potential to expand services without injecting additional resources into the system. Districts that were more urbanized and had a higher proportion of educated women were more technically efficient. Improved cooking methods and donor funding had no significant effect on efficiency.

Conclusion: With the pressing need to accelerate progress in population health, decision makers must seek efficient ways to deliver services to achieve universal health coverage. Understanding the factors that drive performance and seeking ways to enhance efficiency offer a practical pathway through which low-income countries could improve population health without necessarily seeking additional resources.

Key words: Technical Efficiency; Scale Efficiency; Data Envelopment Analysis; Health Systems Performance

Strengths and Limitations of Study

- The study measures technical and scale efficiency at the district level, the lowest health system management unit in most developing countries
- Data envelopment analysis is used to determine sources of inefficiency in the health system
- The study covers only maternal and child health, although the health system also encompasses other broader programmatic areas

Introduction

The decentralization of health services has been pivotal in efforts to promote universal health coverage across the developing world [1–3]. There are many drivers of this trend, but improvements in service delivery remains an implicit motivation in most decentralization efforts [2, 3]. This is anchored mainly around the ideals and principles of local ownership and accountability in service delivery, as well as meeting key health system goals with respect to equity, efficiency and responsiveness [1-4].

As in most other countries, Zambia has embraced a decentralized health system model since 1992 as a pathway towards equitable access to health services for its population [3,4]. This entailed the devolution of key decision-making and implementation functions to the provincial and district level, where stewards were assigned specific roles aimed at meeting national health policy objectives. Consequently, health resources were directed towards districts, which were given primary responsibility in the delivery of key health services to meet various local population health needs [3,5–7].

In this arrangement, the central government is largely focused on setting national priorities and allocating health resources to subnational units based on projected health needs. In practice, this involves the Ministry of Health (MOH) providing budget ceilings to all the district health offices (DHO), which then make their own plans and budget for their activities in alignment with local projected health needs, bearing in mind the budget ceiling [3, 5]. Meanwhile, donor organizations channel their funding primarily through non-governmental and faith-based organizations involved in health service provision at the district level [4, 6, 8]. The Provincial Health Offices occupy an intermediate position between the national and district levels and mainly serve in an oversight role for the districts nested within their respective jurisdictions [3,5,6]. The organization of the health system is aimed at ensuring equity in health service delivery, a core health objective of the government of Zambia [5–8].

Despite these efforts, an in-depth investigation of the country's health system performance reveals wide subnational heterogeneity in goal attainment. This underscores the need to understand the root cause of the differences in performance across subsystems so that the lessons drawn from high-performing sub-units can be informative for those that are lagging behind [3,4,7–9]. A systematic and objective comparison of goal attainment and resource allocation across health sub-units in Zambia is timely. The results could provide a valuable benchmarking framework in the effort to drive the country's health systems towards better performance [4,9,10].

In this paper, we make a systematic comparison of performance across districts and provinces in Zambia, paying attention to the priority area of child survival as a key health system outcome. Health intervention coverage for maternal and child health services is used as the measure of health system output, whereas the human and financial resources allocated to districts are considered the health system inputs. Further, we seek to demonstrate how data envelopment analysis (DEA) [11] can be applied in efficiency benchmarking and comparative performance assessment for a decentralized health system.

Conceptual Framework

The conceptual framework proposed here borrows its fundamentals from the World Health Organization (WHO) Health System Framework, which effectively connects health inputs with health outputs, processes and outcomes [2]. The framework identifies six discrete pillars that must function in tandem to meet expected health goals [2,4,8–10]. The six pillars of a well-functioning health system include the following: good health service provision, adequate and progressive health financing, well-functioning human resources, good governance and leadership, a well-functioning health information system, and access to and equitable distribution of essential medicines and health technologies [2].

In our analysis, we have focused on human resources and health financing as the key health systems inputs underlying the production function used in the estimation of efficiency scores. Meanwhile, health intervention coverage is the intermediate health system output through which changes in health outcomes (in this case mortality among children under 5 years of age) are realized. Health intervention coverage was constructed as a composite metric comprising DPT3 and measles immunizations, skilled birth attendance, and malaria prevention. The approach employed in the construction of this metric and its merits are further discussed in the methods section.

We selected under 5 mortality rate (U5MR) in our assessment of district health system performance, as it is a key indicator used to monitor progress towards the reduction of child mortality rates, which was a key objective of the Millennium Development Goals (MDGs). This indicator is further recognized as a good measure of overall population health, particularly in developing countries. Meanwhile, our health intervention coverage – as a measure of health system output – is composed of essential maternal and child health interventions that are critical for child survival in most developing countries in the tropics [4, 8]. However, given that health outcomes depend on a variety of factors, some of which are under the control of the health sector and some of which are not, we remain cognizant of the fact that there may not be a direct relationship between improvement in health system inputs and the achievement of better health system outputs and health outcomes [11]. Another point that deserves equal attention with regard to the study is the fact that efficiency estimates refer to the efficiency of an output (or an outcome) for a given level of input; they do not refer to the level of the output (or outcome) itself. In other words, it is still possible for a district or a country to be fully efficient and yet have lower output and/or outcome levels [12]. We have attempted to explore this further in the assessment of district health system performance.

Methods

In the definition of efficiency, a distinction should be made between technical, allocative, and scale efficiency measures [13-15]. In this study, only technical and scale efficiencies were considered, mainly because the input prices needed for the estimation of cost functions were not available to us [12, 14]. To estimate the efficiency scores, we employed the Banker, Charnes, and Cooper (BCC) formulation of the DEA model. The choice of the BCC approach is partially guided by the fact that all our variables were ratio-based, and we endeavoured to take economies of scale into account in the analysis. In addition, similar to all other DEA models, the BCC model handles multiple inputs and outputs, an approach that is particularly suited to complex fields such as health systems [13,15], in which there is a multidimensional mix of input and output variables that have to be considered simultaneously [15-18]. Further, we applied the approach developed by Charnes, Cooper and Rhodes (CCR) to enable us to decompose the overall efficiency score into scale and pure technical efficiency.

Given that each decision-making unit (DMU) may face locally unique conditions, the DEA approach assesses each unit separately, assigning a specific weighted combination of inputs and outputs that maximizes its efficiency score [13,15]. Algebraically, this is achieved by solving for each DMU (district) the following linear programming problem [15].

$$\max_{u,v} \left(\frac{\sum_{o=1}^{o} u_o \times y_{o0}}{\sum_{i=1}^{i} vi \times k_{i0}} \right)$$

$$\text{subject to: } \frac{\sum_{o=1}^{o} u_o \times y_{on}}{\sum_{i=1}^{i} vi \times k_{in}} \leq 1 \quad n = 1, \ldots \ldots N$$

Where

y_{o0} = quantity of output "o" for DMU_0

u_o = weight attached to output o, u_o > 0, o = 1, …….., O

k_{i0} = quantity of input "i" for DMU_0

v_i = weight attached to input i, v_o > 0, i = 1, …….., I

The equation is solved for each DMU iteratively (for n=1, 2,…, N); therefore, the weights that maximize the efficiency of one DMU might differ from the weights that maximize the efficiency of another DMU [17, 18]. Theoretically, these weights can assume any non-negative value, whereas the resulting technical efficiency scores can vary only within a scale of 0 to 1, subject to the constraint that all the other DMUs also have efficiencies between 0 and 1.

However, the ratio formulation expressed above leads to an infinite number of solutions, because if (u^*, v^*) is a solution, then (αu^*, αv^*) is another solution [15, 17, 19, 20]. To avoid this problem, one can impose an additional constraint by setting either the denominator or the numerator of the ratio to be equal to 1 (for example, v'xj = 1), which translates the problem to one of either maximising weighted output subjected to weighted input being equal to 1 or of minimising weighted input subjected to weighted output being equal to 1 [15, 21]. This would lead to the multiplier form of the equation as expressed as follows [15, 19, 20]:

$\max_{\mu,v} \; (\mu' y_j)$,

Subject to:

$v' x_j = 1$

$\mu' y_j - v' x_j \leq 0, \; j = 1,2 \ldots J$

$\mu, v \geq 0$

This maximization problem can also be expressed as an equivalent minimization problem [15, 19].

Technically, a DEA-based efficiency analysis can adopt either an input or output orientation. In an input orientation, the primary objective is to minimize the inputs, whereas in an output orientation, the goal is to attain the highest possible output with a given amounts of inputs. In our case, an output-oriented DEA model was deemed more appropriate based on the premise that district health teams have an essentially fixed set of inputs to work with at any given time [3,5,6]. In other words, the district health system stewards would have more leverage in controlling outputs through innovative programming rather than by raising additional resources.

As performance and institutional capacity are expected to vary across districts [4], a variable returns to scale (VRS) approach was also considered more relevant to the study setting. This approach allows for economies and diseconomies of scale rather than imposing the laws of direct proportionality in input-output relationships as espoused in a constant returns to scale (CRS) model [16-22]. A VRS model also offers the advantage of decomposing overall technical efficiency into pure technical efficiency (PTE) and scale efficiency (SE), which is essential in locating the source(s) of differences in performance across production units [16–18].

The analyses were performed using R version 3.2.1, specifically the r-DEA package that has the capability to combine input, output, and environmental variables into one stage of analysis. This package implements a double bootstrap estimation technique to obtain bias-corrected estimates of efficiency measures, adjusting for the unique set of environmental characteristics under which different DMUs are operating [11, 23]. To obtain robust estimates, we bootstrapped the model 1,000 times and generated uncertainty around the estimates [23, 24]. The same approach was used to generate robust DEA efficiency scores corresponding to health intervention coverage, applying the same input and environmental variables.

Data Sources

We used data from the Malaria Control Policy Assessment (MCPA) project in Zambia, which compiled one of the most comprehensive district-level datasets of U5MR, health intervention coverage and socioeconomic indices in the country based on standardized population health surveys [4,8]. For both indicators, to capture the most recent period for the country, the data representing the year 2010 were used.

In our DEA model, U5MR was used to measure district health system outcomes. To measure the outcome, output and inputs in the same direction in such a way that “more is better”, we converted the probability of dying before five years of age (which is conventionally known as the under-five mortality rate) into the probability of survival to age 5. This was accomplished by simply subtracting the reported under-five mortality rate per 1000 live births from 1000 [11, 25]. Health intervention coverage was a composite metric that consisted of the proportion of the population in need of a health intervention who actually receive it [4, 8].

The composite metric consisted of DPT3 and measles immunizations, skilled birth attendance, and malaria prevention. For malaria prevention, we included an indicator approximating malaria prevention efforts across districts, i.e., a combination of insecticide treated net (ITN) ownership and indoor residual spraying (IRS) coverage. The average of all 5 health interventions for each district was used to represent health intervention coverage [4]. This innovative method of data reduction by combining a range of health interventions has the advantage of reducing the number of variables that are entered into the model. This in turn helps to maintain a reasonable balance between the number of DMUs and the input and output variables. This is required to avoid a scarcity of adjacent reference observations or “peers,” which if not addressed would lead to sections of the frontier being unreliably estimated and inappropriately positioned [15, 16,18].

For the inputs portion, we obtained a dataset of annual operational funds from both the governments of and donors to each of the 72 districts for the year 2010. These data are available through the Directorate of Health Policy and Planning (DHPP) of the Ministry of Health

[8]. Using population data from the Central Statistics Office of Zambia, we calculated the total population-adjusted funds disbursed to each district. We also obtained data from the Ministry of Health on the human resource complement for the year 2010, which covered the medical professionals (doctors and clinical officers) and nurses (including midwives) in each district and adjusted the data for the district population.

In addition, we included the mean years of education among women aged 15-49 years, the proportion of district funds originating from donors, household access to electricity and the proportion of households with improved cooking methods as environmental variables that are external to district health units but nonetheless affect the performance and efficiency levels of the health system. These variables were chosen based on their importance in addressing the key global health targets related to maternal and child health in Africa [1–3]. Donor funding is a major feature in African health systems and has been the subject of major debate in efforts to strengthen health systems. Similarly, the relationship between health and education, particularly among women, has been extensively documented [2–4,8]. Both datasets were obtained from the MCPA database.

Ethical approval

Permission to conduct the study was obtained from the Ministry of Health, Zambia. Since our study used only de-identified secondary data, we were granted an exemption from the IRB, University of Zambia: IRB00001131 of IROG000074.

Results

Descriptive statistics

Table 1 presents descriptive statistics for the variables used in the study. The range for both inputs and outputs is quite wide. For example, the under-five mortality rate across districts varies between 87.16 deaths per 1000 live births and 161.96 deaths per 1000 live births, whereas health intervention coverage varies from 44.20% to 93.42%. Similar patterns are apparent for the health workforce and financing indicators, for which the distribution of nursing personnel ranged from 5.16 nurses/1000 population to 33.03 nurses/1000 population, whereas total funds to districts ranged from 4.24 million ZMK/1000 population to 23.77 million ZMK/1000 population. This suggests that at the subnational level, the Zambian health system is quite heterogeneous.

Table 1: Summary statistics of the variables

	Variable	Units	Mean	Standard deviation	Min	Max
Outcomes	Under-five mortality rate	*Deaths per 1000 live births*	115.61	(14.66)	(87.16)	(161.96)
	Under-5 survival rate	*Per 1000 live births*	884.39	(14.73)	(838.04)	(912.84)
Outputs	Health intervention coverage[ii]	*Percentage %*	67.09	(10.99)	(44.20)	(93.42)
Inputs	Total funds	*Millions of Zambian kwacha per 1,000 population*	13.60	(3.55)	(4.24)	(23.77)
	Medical personnel	*Medical personnel[iii] per 1,000 population*	6.96	(3.34)	(.92)	(18.23)
	Nursing personnel	*Nursing personnel[iv] per 1,000 population*	12.72	(5.76)	(5.16)	(33.03)
Environmental	Proportion of donor funds	*Percentage %*	38.43	(5.21)	(31.39)	(57.21)
	Proportion of households with access to electricity	*Percentage %*	13.23	(17.06)	(0.19)	(61.29)
	Proportion of households with improved cooking	*Percentage %*	10.26	(14.55)	(0.33)	(53.77)
	Average years of education for women aged 15-44	Years	5.72	(1.60)	(2.93)	(9.51)

[ii] Health intervention coverage is a composite metric comprising 5 health interventions
[iii] Medical personnel includes both medical doctors and clinical officers (medical assistants)
[iv] Nursing personnel includes both registered nurses and midwives

Table 2 displays provincial comparisons of the input, output and outcome variables, revealing further heterogeneity across the country. For instance, in the predominantly urbanized Copperbelt province, health intervention coverage was as high as 81.05% (95%CI: 75.31-86.78). In comparison, the predominantly rural North-Western province had a coverage rate of 61.64% (95%CI: 53.80-69.48). Even within provinces, there was significant heterogeneity given that all the provincial estimates of health intervention coverage had wide confidence intervals of more than 10 percentage points. This trend further underscores the differences in goal attainment across the districts in the country. Similar differences were also observed with respect to the under-five survival rate: the provincial estimates revealed a wide gap across provinces, with the Southern province topping the list with 898.14 survivors per 1000 live births (95%CI: 892.64-903.63) and the Northern province lagging with 869.82 survivors/1000 live births (95%CI: 862.25-877.38).

Table 2: Summary of variables by province

Provinces	Under-five mortality rate	Under-five survival rate	Health intervention coverage	Total funds	Medical personnel	Nursing personnel	Districts
Units	*Deaths per 1000 live births*	*Per 1000 live births*	*Percentage %*	*Millions of Zambian kwacha per 1,000 population*	*Medical personnel per 1,000 population*	*Nursing personnel per 1,000 population*	*Number*
Central	109.46 (103.00, 115.91)	890.54 (884.09, 897.00)	63.92 (54.41, 73.42)	12.70 (11.97, 13.44)	7.75 (5.63, 9.87)	12.02 (6.53, 17.51)	(6)
Copperbelt	111.07 (106.40, 115.75)	888.93 (884.25, 893.6)	81.05 (75.31, 86.78)	10.27 (7.39, 13.16)	8.08 (6.36, 9.80)	16.83 (14.89, 18.77)	(10)
Eastern	126.35 (120.73, 131.97)	873.65 (868.03, 879.27)	69.96 (65.41, 74.50)	14.58 (12.71, 16.46)	6.64 (4.26, 9.02)	10.26 (8.26, 12.27)	(8)
Luapula	127.99 (115.62, 140.36)	872.01 (859.64, 884.38)	62.18 (57.94, 66.43)	15.26 (13.94, 16.57)	5.99 (4.44, 7.54)	10.11 (7.35, 12.88)	(7)
Lusaka	111.76 (101.84, 121.69)	888.24 (878.31, 898.16)	77.00 (71.96, 82.05)	11.26 (2.56, 19.96)	7.65 (4.36, 10.94)	15.59 (3.60, 27.58)	(4)
North-Western	106.64 (101.07, 112.22)	893.36 (887.78, 898.93)	61.64 (53.80, 69.48)	16.52 (14.59, 18.45)	6.89 (3.77, 10.00)	15.98 (10.65, 21.32)	(7)
Northern	130.18 (122.62, 137.75)	869.82 (862.25, 877.38)	62.52 (58.38, 66.67)	13.76 (12.57, 14.96)	3.66 (2.40, 4.93)	8.82 (6.72, 10.93)	(12)
Southern	101.86 (96.37, 107.36)	898.14 (892.64, 903.63)	65.08 (58.06, 72.10)	12.79 (11.49, 14.10)	9.27 (7.05, 11.50)	14.80 (11.66, 17.94)	(11)
Western	110.49 (99.99, 120.99)	889.51 (879.01, 900.01)	62.24 (54.07, 70.42)	15.73 (14.67, 16.79)	7.73 (5.70, 9.77)	11.40 (7.80, 15.01)	(7)

Note: 95% confidence intervals in parentheses, these were calculated under the normal distribution assumption

Overall efficiency, pure technical efficiency, and scale efficiency

Figure 1 shows the estimates of overall technical efficiency (OTE) scores that were obtained using an output-oriented, bias-corrected DEA model across the 72 districts of Zambia with the under-five survival rate as our outcome indicator. A value of 1 indicates that a district produces at the frontier; the lower the value, the farther the district is from the efficient frontier. Consistent with the input, output and outcome indicators shown in Table 1, the results shown in Figure 1 portray a deeply heterogeneous picture in terms of overall technical efficiency across subnational units. For example, both the worst and best performing districts, Luangwa at 31.0% (95%CI: 29.5-33.0) and Kafue at 88% (95%CI: 79.2-97.1), respectively, are found in the predominantly urban province of Lusaka.

Only 22 (31.0%) of the districts in the country (predominantly those in the Northern and Lusaka provinces) had efficiency scores above 70%. The next tier of top performers, with an overall technical efficiency score between 60% and 70%, showed a mixed picture but also had predominant representation from the Copperbelt province and other districts in the northern and eastern parts of the country, which suggests a phenomenon of spatial clustering in performance in the country. The average efficiency score for the country as a whole was 61.5% (95%CI: 58.2-64.8), which suggests that there is significant potential for further improvement without the need for additional resources.

Figure 2 shows that there was a strong association between the overall technical efficiency scores for under-five survival (outcome) and the overall technical efficiency scores for health intervention coverage (output). This means that efficient attainment of health intervention coverage is strongly predictive of how efficiently districts in Zambia perform in meeting their child survival objectives. However, although this trend is observed in most districts, there are some that deviate from it, which raises further questions into the role of environmental factors that are beyond the control of the health system.

The OTE can be further decomposed into pure technical efficiency (PTE), which is a measure of managerial performance in the production process, and scale efficiency (SE), which is the ability to choose the optimum size of resources in production. Figure 3 shows the PTE, SE, and OTE scores for the nine provinces of Zambia. OTE appears to be higher in the Northern, Lusaka and Eastern provinces. However, the Northern and Lusaka provinces are also in the lead in terms of PTE, whereas the Southern and North-Western provinces are in the bottom tier. Meanwhile, SE appears to be generally high across the country, with the Lusaka province leading with 100%.

The efficiency measures discussed above consider only the use of resources or the scale of operation and do not directly address outcomes. For instance, it is possible for districts or provinces to have lower service coverage but perform better in the management of resources available to them, and vice versa. Figure 4 shows a comparison of PTE and health intervention coverage across the 72 districts of Zambia, with the quadrants defined as the means of each estimate. The PTE scores presented in the figure provide an opportunity for policymakers and local decision makers to examine the effect of managerial competence without the diluting effects of scale of operation on performance.

In Figure 4, 37 of the 72 districts fall into the high managerial performance category, of which 18 have managed to combine high managerial efficiency with high health intervention coverage. However, in the remaining 19 districts in this category, health intervention coverage is still low despite high efficiency. In contrast, there are 17 districts in which both managerial performance and coverage remain low. The average pure technical efficiency score was 66.3% (95%CI: 62.9-69.7), whereas the actual scores ranged between 31.3% (95%CI: 31.0-32.9) and 89.5% (95%CI: 83.7-96.8).

Further, Figure 5 shows a comparison between under-five survival rates across districts and PTE. It is clear that high performance in terms of PTE in a given district does not necessarily translate to better health outcomes. This is observed in districts such as Chiengi and Chilubi, which score high in terms of PTE but trail their peers in under-five survival rate.

Effects of environmental factors on overall technical efficiency

Table 3 presents results of a regression analysis to estimate the effect of environmental factors on the OTE for under-five survival rate at the district level. The results were obtained using the bias-corrected, two-stage estimation process for the four environmental variables we chose for our analysis. The results suggest that the channelling of donor funding in Zambia seems to have an insignificant effect on technical efficiency. Meanwhile, female education had a significant positive effect, confirming the interdependencies between health and education noted in previous studies.

Table 3: The effects of the environmental variables

	Coefficients
Constant	0.85*
Female education	0.18**
Household access to electricity	-0.03
Proportion of funding from donor sources	-0.09
Household access to improved cooking	0.02

* $p < 0.05$, ** $p < 0.01$

Discussion

With the push for universal coverage across the developing world and the existence of uncertainties regarding future global investments in health, the question of efficiency in health service delivery has become increasingly important. This paper attempted to evaluate the extent of pure technical, scale, and overall technical efficiencies in Zambia using cross-sectional data from 72 districts. In addition, an attempt has been made to investigate the role of environmental factors, specifically donor funds and maternal education, on the efficiency of maternal and child health in the country. This effort is particularly relevant given the finite nature of available health resources in the face of rising health needs [1,2,4,8].

DEA is an attention-directing managerial technique [15-22, 26]. By evaluating the relative efficiency of subnational units, it locates trouble spots in the service delivery system and identifies potential areas for further improvement. This is based on the understanding that in a decentralized health system, subnational units have a far-reaching impact on the overall performance of the health system [4,7,9]. Through this framework, policymakers can objectively benchmark the performance of the district health system with the aim of fostering peer learning and accountability.

DEA has been extensively used to assess the performance of health systems across different settings. For instance, Ortega, Sanjuan and Casquero [11] used DEA to analyse the impact of income inequality and government effectiveness on the efficiency of health inputs to improve child survival in developing countries. Kirigia, Sambo and Lambo [27] applied DEA to measure technical and scale efficiency across 55 public hospitals in South Africa. Kirigia, Emrouznejad and Sambo [28] also used the DEA methodology to measure the relative efficiency of 54 hospitals in Kenya. In Ghana, Alhassan et al. [14], applied DEA to estimate the technical efficiency of private and public health facilities accredited by the National Health Insurance Authority. In addition, Masiye F. [29] has used DEA to measure the technical and scale efficiency of hospitals in Zambia.

Building on existing evidence regarding the application of DEA in Zambia, the findings from the present study reveal significant heterogeneity in performance across the country. It is clear that overall technical efficiency in the production of health outcomes is strongly correlated with efficiency in the production of health outputs, given the same inputs. However, as noted earlier, efficiency estimates refer to the efficiency of an output (or an outcome) for a given level of input; they do not refer to the level of the output (or outcome) itself. In other words, it is possible for a district or a country to be fully efficient and yet have lower output and/or outcome levels [11, 12].

Low performance in the districts and provinces was due largely to both poor input utilization (i.e., pure technical inefficiency) rather than to the failure to operate at the most productive scale size (i.e., scale inefficiency). The average PTE score for the country was observed to be 66.3%, which implies that 33.7% percentage points of the approximately 38.5% overall technical inefficiency in the country is attributed to district health managers who are not following appropriate management practices and who are selecting incorrect input combinations. The remaining shortfall in overall inefficiency appears to be due to the inappropriate scale of operations. This is consistent with the findings of Masiye F. [29], which established that a significant proportion of hospitals in Zambia were technically inefficient.

Specifically, urban districts seemed to be more scale efficient than their rural counterparts, probably as a result of having a densely populated environment in which the marginal cost of increasing population coverage is significantly lower than in rural areas. Similarly, urban residents tend to have better access to health services, in both physical and financial terms, than their rural counterparts, resulting in higher utilization of the available services. In contrast, due to access challenges in rural areas, there is often low utilization of the available health services.

We showed that 37 of the 72 districts fall into the high managerial performance category, of which 18 combine high managerial efficiency with high health intervention coverage. In the remaining 19 of the 37 districts in this category, health intervention coverage is still low, but this had no relation to the efficiency with which managers combined the inputs at their disposal, suggesting that for this group of districts, the only way to improve coverage would be to put additional resources into the system. In contrast, in the remaining 17 districts, where both PTE and coverage of services remained low, improvements in health intervention coverage should first and foremost focus on improving managerial underperformance (i.e., managerial inefficiency) in organizing the inputs at their disposal, followed by introducing new resources, especially in areas where coverage rates are extremely low. A similar interpretation applies when considering health outcomes in districts such as Chiengi and Chilubi in which the efficiency level is already high but outcome levels remain low; further progress in child survival can only be realized by investing new resources in these areas.

We further demonstrated that the relationship between health system inputs, outputs and outcomes is complex [11]. Although there is a strong association between the efficiency measures in the production of health outputs and health outcomes, there are some deviations that need further investigation. Health systems are mainly responsible for organizing the available resources to maximize health outputs with the hope that these outputs will translate into better health outcomes. However, the environmental factors in the district within which a health system operates also play a significant role in determining outcomes.

Therefore, in health programming, it is equally important to not ignore the social determinants of health, particularly the educational status of women, which is shown to have a positive impact on the efficiency of the health care system. Educated women are likely to be aware of and demand appropriate health services when they need them. In fact, the variables that have been included in the composite metric—skilled birth attendance, childhood immunizations and malaria prevention—are all considered crucial for maternal and child health in most of Africa [4]. Therefore, it is only natural that educated women would have a greater awareness of and ability to seek and utilize these important health services when they are available than less educated women. The cumulative effect at the district level would also translate to higher utilization and therefore efficient service provision in districts where women are more educated. This would ultimately translate to better survival in areas where care-givers are better educated.

While donor funding has been a dominant feature of the African health systems landscape in recent years and has contributed significantly to the scaling up of priority health interventions, many have raised questions regarding its effectiveness [2,30–32]. From this analysis, we cast doubt on whether donor funds are being channelled and utilized optimally at the district level. The reasons that donor funding had no significant effect on efficiency could be explained by various factors. First, districts with limited institutional capacity might lack the implementation capacity to use the available funds to deliver required health services effectively. This would lead to inefficiency within the health system, whereby districts would have large amounts of money without the ability to deliver required services. Second, donor funds are often earmarked for specific programmes such as malaria, HIV/AIDS, and tuberculosis [3]. In such vertical programming, the donor-funded programmes might reduce other health programs' implementation capacity, leading to sub-optimal performance in other key programme areas such as skilled birth attendance and other preventive services that are relevant to maternal and child health care.

Our analysis is not, however, without limitations. First, we have focused on a limited number of health system outputs (i.e., maternal and child health indicators), despite the fact that a health system produces many more outputs covering different programmatic areas. Similarly, due to data availability constraints, we have also considered a limited set of health inputs and non-discretionary variables to explain the differences in efficiency across districts. Moreover, in our comparison of relative efficiency across districts, we did not fully account for important structural and organizational factors such as leadership and governance that play a key role as determinants of performance [10,30–32]. These limitations call for an in-depth assessment that will seek to further explain the observed differences in performance across districts in Zambia.

The DEA approach implemented in the present study is also not without limitations; the major drawback is the sensitivity of the derived estimates to the methods and the presence of outliers in the data. Although these issues cannot be circumvented altogether, we have examined the sensitivity of the derived estimates using both internal and external consistency checks on the data. Specifically, we fitted 72 separate DEA models, each of which had one fewer observation—which was achieved by removing one district from our analysis—and then compared the root-mean-square error (RMSE) and pairwise correlations of the efficiency scores across these models. We have also re-estimated the technical efficiency scores using a parametric approach following the stochastic frontier model and have compared the outcome with our original DEA-based model. These results (not shown here) confirmed that our efficiency estimates are unlikely to have been biased by outliers, as the RMSE for the different models is less than 2% in most cases, and the pairwise correlation coefficients estimated using the alternative models showed a strong significant correlation.

Conclusion

The WHO underscores that efficiency in health service delivery is a key attribute of a performance-oriented health system [2,10,29,30]. Therefore, with many health systems facing resource constraints, decision makers must strive to understand the factors that drive health system performance and seek ways to improve efficiency. Paying attention to factors such as stewardship, resource allocation and management is particularly useful if meaningful progress towards universal health coverage is to be realized in low- and middle-income countries.

Competing Interests

All the authors declare that they have no competing interests.

Authors' contributions

TA conceptualized the study and extracted all the relevant data. TA and YK developed the model, carried out the analyses and drafted the report. FM, AL, HL and AH critically read the draft and provided comments for the preparation of the final manuscript. All the authors read and approved the final manuscript.

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Data Sharing

The main datasets supporting the conclusions of this article are available upon request and with written permission from the Ministry of Health of the Government of the Republic of Zambia.

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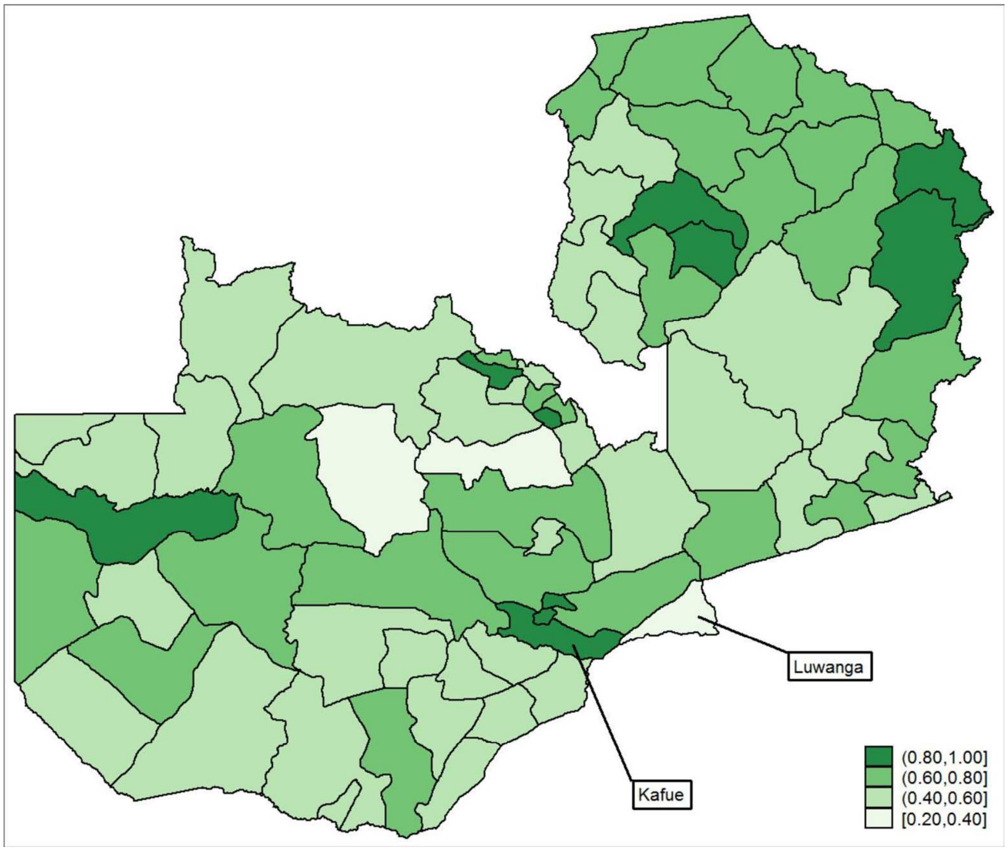
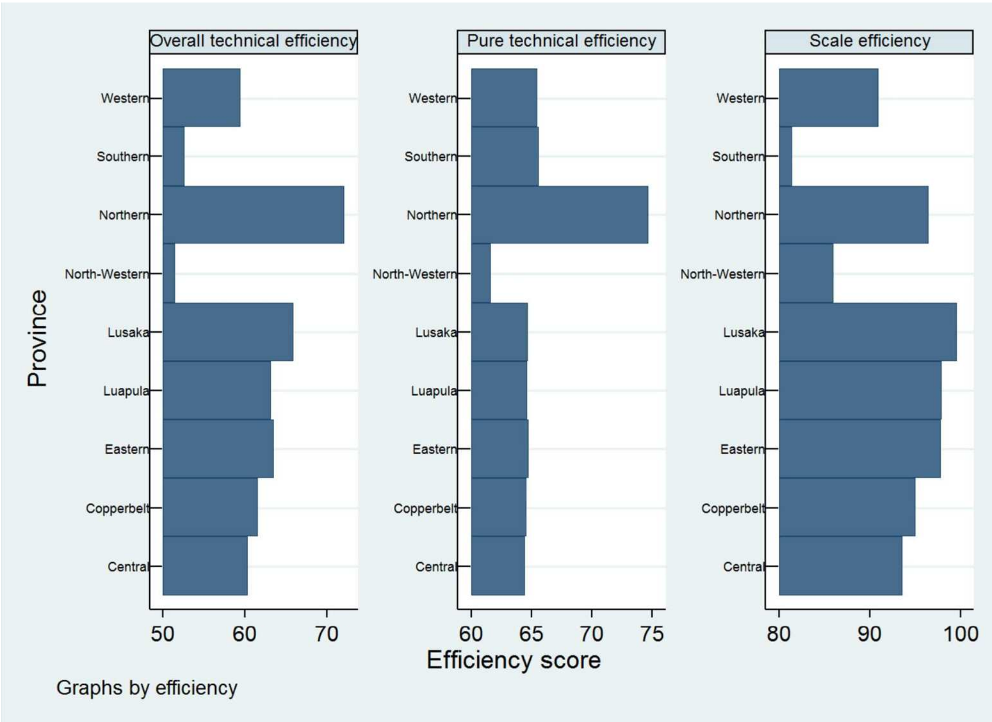
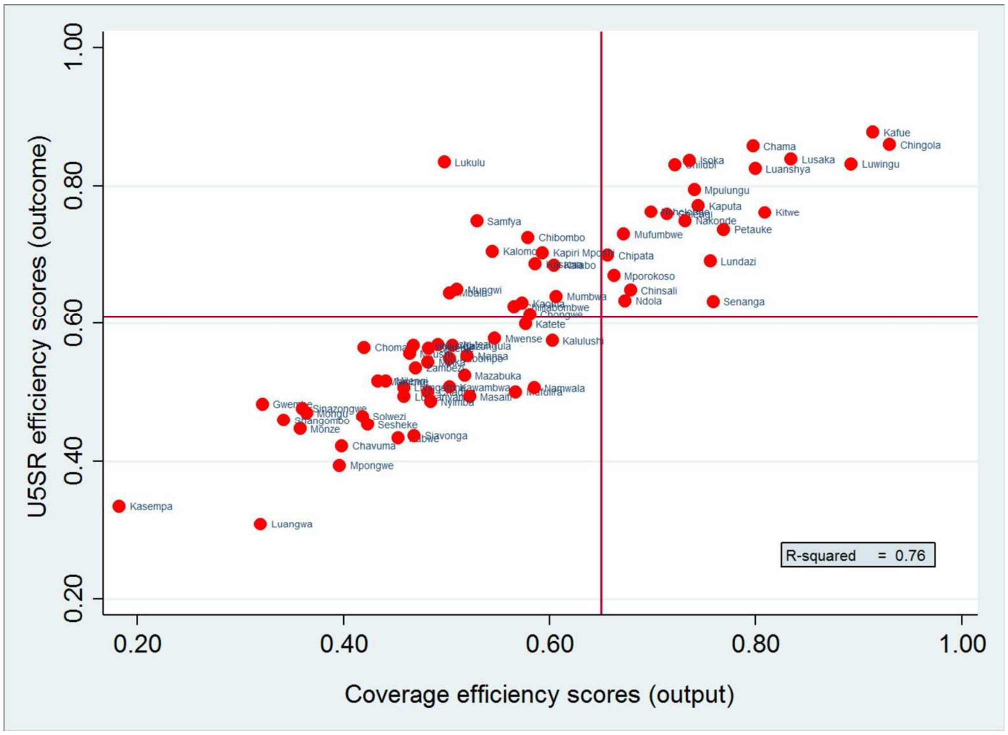


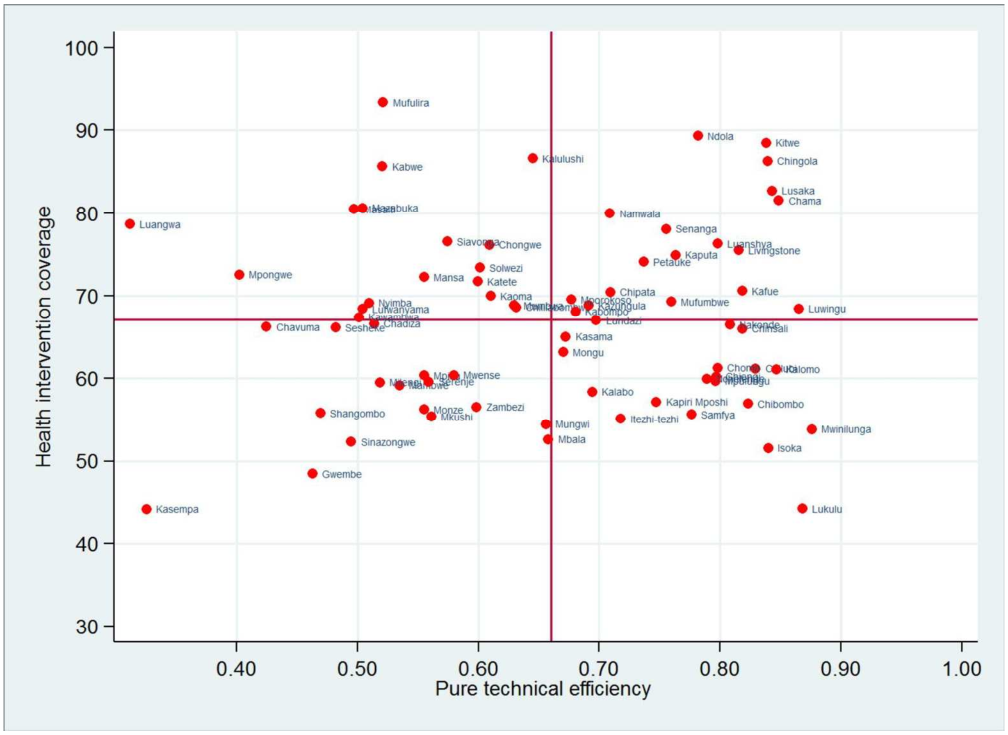
Overall technical efficiency across districts
Figure 1
126x106mm (300 x 300 DPI)



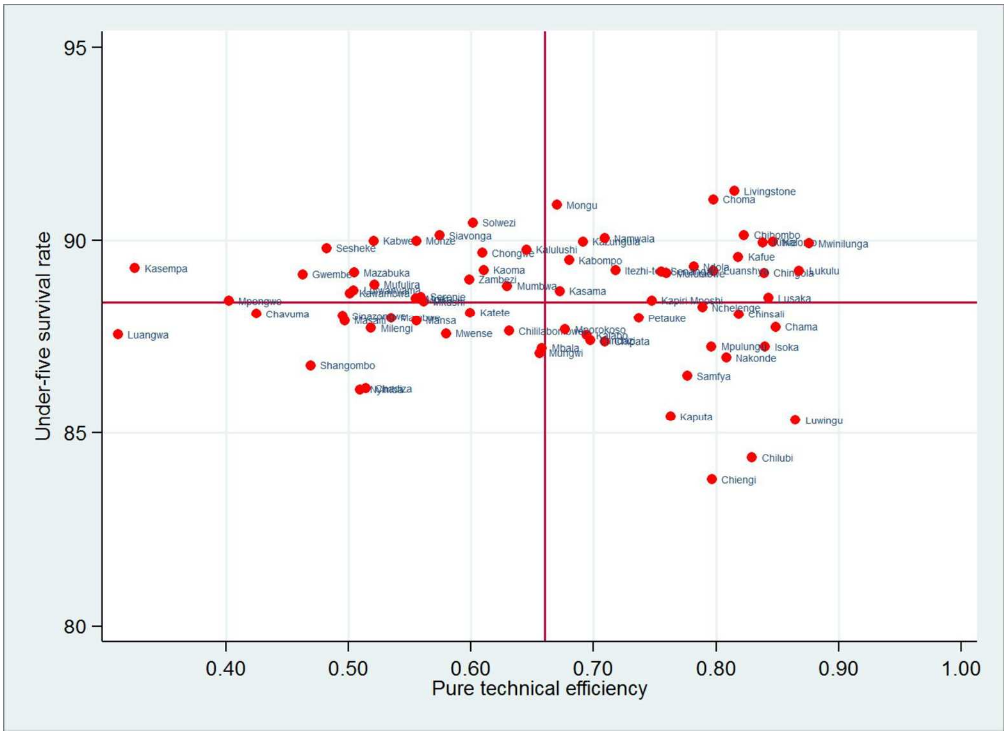
Provincial efficiency ranking
Figure 2
145x106mm (300 x 300 DPI)



A comparison of under-five survival and health intervention coverage technical efficiency
Figure 3
146x106mm (300 x 300 DPI)



A comparison of pure technical efficiency and health intervention coverage
Figure 4
146x106mm (300 x 300 DPI)



A comparison of pure technical efficiency and under-five survival

Figure 5

146x106mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract This has been included in the main article. See pages 1 and 2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found This has been included – see page 2 of the main article
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported This is included in page 3 of the main article
Objectives	3	State specific objectives, including any pre-specified hypotheses Aspects of this are included in page 3, paragraph 5 of the main article
Methods		
Study design	4	Present key elements of study design early in the paper In pages 4 and 5 of the main article we have introduced data envelopment analysis –as the main method used in our analysis
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection Aspects of the study setting have been included in pages 3-(introduction), and 6 (data sources and ethical approval)of the main article
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up N/A *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls N/A *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants The study employs cross-sectional data on health system outputs, inputs and outcomes collected from secondary sources. There were no participants to this study as the analysis is focused at a district level and uses aggregate data.
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed N/A *Case-control study*—For matched studies, give matching criteria and the number of controls per case N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable This is covered in page 6, where we identify main variables used in the analysis as well as define our data sources in detail.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group

		Defined in page 6 of the main article
Bias	9	Describe any efforts to address potential sources of bias In our methodology – we have adopted a data envelopment analysis framework that propagates uncertainty in the estimation. The efficiency scores presented have confidence intervals estimated from 1000 sample draws from the data used in the analysis
Study size	10	Explain how the study size was arrived at Ours is a nationwide study and covers all districts in the country.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why This was a quantitative study based on secondary data analysis. More details available in the methodology section, pages 4 and 5
Statistical methods	12	*(a)* Describe all statistical methods, including those used to control for confounding Explained in the methods section – page 4 and 5
		(b) Describe any methods used to examine subgroups and interactions We have estimated differences in efficiency between provinces and between districts (within provinces) and obtained confidence intervals to test if the differences were statistically significant or not.
		(c) Explain how missing data were addressed The data used for analysis were balanced. We didn't have missing data.
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy N/A
		(d) Describe any sensitivity analyses See page 15in the discussion section. We have conducted bootstrap type sampling approach to test sensitivity.

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed As stated earlier the study does not involve individuals; it is based on district level data.
		(b) Give reasons for non-participation at each stage N/A
		(c) Consider use of a flow diagram N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders- Aspects of this have been defined in page 6, Data sources
		(b) Indicate number of participants with missing data for each variable of interest N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure N/A
		Cross-sectional study—Report numbers of outcome events or summary measures This has been included in the results section- pages 7-12
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included: Our key results are presented with confidence intervals; see the results section, pages 7-12.
		(*b*) Report category boundaries when continuous variables were categorized N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period. NA. Our analysis is focused on estimating efficiency level, and these are by definition reported in terms of proportions.
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses Defined in the methods section- see pages 7-12
Discussion		
Key results	18	Summarise key results with reference to study objectives Elaborated in the discussion section – page 13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias Limitations of the study – clearly included in pages – 1 and 15 of the main article. The methods section also expounds on the limitations of Data Envelopment Analysis
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence See the discussion section- page 13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results The findings of this study are generalizable to other low and middle income countries. This has been included in the results, discussion and conclusion sections of the main article
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based N/A

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.