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Cost optimisation analysis of the expanded programme for immunisation: balancing equity and coverage in Pakistan

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ABSTRACT

Introduction With limited resources, attaining maximal average health service coverage can be at odds with maximising equity which attempts to promote greater reach among underserved populations. In this study, we examined the trade-offs in immunisation coverage levels and equity for children under 5 years of age in Pakistan across various subpopulations who can be targeted with different combinations of immunisation service modalities.

Methods We conducted a detailed costing exercise across 16 geographically and demographically diverse districts in Pakistan. These data were the basis for (a) technical efficiency benchmarking via Data Envelopment Analysis to identify potential efficiency gains by location, delivery model and cost ingredient; (b) allocative efficiency optimisation modelling to understand how resource allocations could be optimised and to devise recommended budget allocations and operational metrics. Finally, the hypothetical overall efficiency gains attainable were estimated if available resources were allocated with the optimal emphases, and if service delivery models operated at productivity levels at the benchmarked frontier of efficiency.

Results Benchmarking suggests that ~44% of delivery models are running efficiently and 37% are highly inefficient. While coverage and equity are usually at odds, surprisingly, the optimisation modelling revealed that substantial improvements in equity between subpopulations does not necessarily cost very much in overall immunisation coverage: theoretically, equity can be achieved while still attaining close to maximal immunisation coverage. Overall, analyses suggest greater emphases should be placed on outreach delivery models which particularly target rural areas and slum populations.

Conclusion The unit cost differentials within districts are not sufficiently large for there to be a large reduction in potential Fully Immunised Children coverage if one focuses on maximising equity. However, reallocations of programme budgets can have a significant impact on equity outcomes, particularly at current low spending amounts. Therefore, it is recommended to address equity as the key objective in national immunisation programming.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Although population health indicators are improving in Pakistan, there continues to be high rates of vaccine-preventable diseases in children, associated with relatively low vaccine coverage. With such limited resources available, it is particularly important they are allocated in a way that achieves both high efficiency and equity. The best ways to do this are not always clear.

WHAT THIS STUDY ADDS

⇒ We generate evidence to guide resource deployment of childhood vaccine coverage in Pakistan to maximise either equity or immunisation coverage, and assess the trade-offs between these outcomes. While coverage and equity are usually at odds, surprisingly we found that substantial improvements in equity in coverage levels between subpopulations does not necessarily cost very much in this context: theoretically, it can be achieved while still attaining close to maximal Fully Immunised Children at both the district and provincial levels.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ In practice, budget line items may not need to change substantially (eg, total number of vaccinators) to maximise coverage or equity, but where and how they are deployed for delivery to specific populations could make a substantive difference. The trade-off between equity and coverage is such that reallocation of resources to maximise equity can still achieve close to maximal coverage, but the converse is not necessarily true when resources are limited. Therefore, maximisation of equity should be a priority, through greater efforts to reach rural and slum populations and to promote the delivery models that service them.

INTRODUCTION

Vaccination is one of the greatest innovations in global health, responsible for much of the decline in the under-5 mortality rate and is one of the highest priorities for disease control and long-term economic development in any country. According to the WHO and the United Nations Human Rights Council,[1] immunisation against the major infectious diseases constitutes one of the six universal minimum standards of health service provision, and long-term implementation strategies should involve targeting by type of service, community or clear social categories as a practical and effective way of redressing inequalities in health.

Although population health indicators are improving in Pakistan, there continues to be high rates of vaccine-preventable diseases (VPD) in children, associated with relatively low vaccine coverage: the latest Pakistan Demographic and Health Survey implemented by the National Institute of Population Studies,[2] found that the percentage of Fully Immunised Children (FIC) aged 12–23 months was just 66% in 2017–2018, ranging across provinces from 29% in Balochistan to 80% in Punjab.[3] Unsurprisingly, health indicators for Balochistan are far below the national level: life expectancy at birth is 63.4 years versus 65.9 for all of Pakistan, the Human Capital Index is 32% versus 41% and 18.3% of children under 5 experience wasting versus 7.1%.[4] Children are also less likely to receive all basic vaccines if they are female, are of order six or higher, live in rural areas, have mothers with low or no educational attainment or are in the poorest household-wealth quintile.[2] Consequently, there have been alarmingly high rates of infant and child deaths, leaving Pakistan as the country with the third highest number of deaths for children under-5 years, with ~400 000 deaths registered in 2019.[5] The mortality rate was 74 deaths per 1000 live births in 2017–2018,[2] almost double that of the global rate of 38 deaths per 1000 live births in 2019.[5] In this paper, we are addressing geographical inequality in Pakistan.

Pakistan's Expanded Programme on Immunisation (EPI) includes the vaccination of children against: tuberculosis (BCG vaccine, single dose at first clinical contact); polio (three doses at 6, 10 and 14 weeks) and pneumococcal (also at 6, 10 and 14 weeks); the pentavalent vaccine for diphtheria, whooping cough and tetanus (DPT), hepatitis B and haemophilus influenza type b (three doses given shortly after birth, within 1–2 months and within 6–18 months) and measles (one dose, soon after 9 months). Its aims are to increase equitable coverage of immunisation services against VPD and to decrease VPD and associated mortality. EPI services are delivered at community and health service delivery institutions: all public-sector health facilities and union councils must have a functional EPI centre that serves the catchment population, while outreach vaccination services are employed to reach those that reside outside the fixed centres' catchment areas. Additionally, mobile vaccination strategies are used for remote and hard to reach areas such as in Balochistan, the largest yet least populated province of the country.

In fiscal year 2018–2019, US$220 million were spent on immunisation in Pakistan;[6,7] this amounts to an average of just $8–12 per child under 5 years of age over this period. With such limited resources, it is particularly important to ensure that the resources are allocated and then spent for the greatest achievable efficiency. In this study, we conducted a costing exercise across 16 geographically and demographically diverse districts in Pakistan. These data were used to identify areas for potential efficiency gains by location, delivery model and cost ingredient using technical efficiency benchmarking via Data Envelopment Analysis (DEA). Allocative efficiency optimisation modelling was then undertaken to understand how resource allocations could be optimised across geographies and delivery models to maximise either equity or FIC coverage, and the trade-offs between these outcomes. These analyses, along with regression-based extrapolated unit costs for all districts-delivery modalities across the country, were used to devise recommended budget allocations and operational metrics by delivery model and district for various total resource envelopes. Finally, we estimated the hypothetical overall efficiency gains potentially attainable if available resources are allocated with the optimal emphases through each delivery model in each district (ie, allocative efficiency), as well as if service delivery models operated at productivity levels at the benchmarked frontier of efficiency (ie, technical efficiency).

METHODS

Immunisation services unit cost estimation substudy

Understanding the (allocative and/or technical) efficiency of a programme, for assessing optimal programming, requires data on the unit costs of delivery. We conducted a unit cost substudy of FIC by geographic area, across 16 districts across all provinces of Pakistan, and within each district over each service delivery modality (EPI static sites, outreach services, municipal and urban EPI services and Supplementary Immunisation Activities). A cost-ingredient approach was taken using WHO guidelines,[8–10] and a secondary data collection survey was implemented to gather complementary data on all cost components, by 'following' the vaccines from importation to the country through to vaccination delivery.

One of the key sources for immunisation cost is expenditure data from Government Financial Management Information System (GFMIS) owned and managed by Controller General of Accounts (CGA), which has a network of provincial and district offices. Expenditure from extrabudgetary resources was taken from the National Immunisation Accounts 2018–2019 (for which information is collected directly from development partners, EPI provincial offices, WHO and UNICEF).

The sampling was based on the sample design for the Pakistan Social and Living Standards Measurement Survey (PSLSM) by the Federal Bureau of Statistics. The four provincial capitals were chosen as they are both large urban areas and also main hubs for vaccine distribution and storage. Another provincially representative city was selected in Sindh and Khyber Pakhtunkhwa (KP), and two others in Punjab. For the rest of the sample, two districts in each province located further away from the provincial capitals were included.

The need for conducting a survey arose from the fact that the data for number of children immunised by the programme, and expenditures, were not available at the national level disaggregated into urban and rural populations. The objective of the survey was to gather data on the types of immunisation facilities, human resources, equipment available by type of facility, the number of children immunised and the allocation of the cost data in each district. The data collection tools were designed to capture FIC coverage of the target population and programme data at union council level to facilitate the separation of the data into rural and urban areas. Survey respondents were both male and female immunisation managers, service providers and vaccinators and data were collected via face-to-face, paper-based interviews as well as secondary financial data collection of the EPI programme. Protocol and Institutional Review Board clearance was obtained from the Pakistan EPI and Polio Programme. The characteristics of the selected districts can be found in online supplemental appendix A.

Due to sample size and selection of self-representative large (urban) districts, the sampled districts within a province are skewed towards urban populations. The overall share of urban in the sampled population is 67% and is higher than Pakistan's overall urban population. Sample design weights were therefore applied to adjust for the larger share of the urban population in the sample and to better reflect the actual share of the urban population of Pakistan.

Costs gathered from survey data were classified into the following groups:

- Group 1: EPI Salary, Travel and Transportation, Communications.
- Group 2: Communications (advertising, exhibitions, conferences, etc), Waste charges, Stationary.
- Group 3: EPI Petrol Oil Lubricants, Transport Repair and Maintenance.
- Groups 4, 5, 6 and 8: Vaccines Boxes, Cold Chain Equipment.
- Group 7: Motorcycles.
- Group 9: Shared Health System Cost.

These costs are directly assigned to the cost objective, that is, the number of FIC. Costs are reported in USD and are converted from PKR based on the average exchange rate in 2018.

Technical efficiency benchmarking via DEA

DEA is a non-parametric technique used to assess the relative efficiencies of a set of decision-making units (DMUs), essentially by benchmarking DMUs against each other, and to estimate the maximum potential output for a given set of inputs.

For the analysis, the combination of in which district a certain vaccine delivery model was implemented and to which target population group made up the components of the DMUs (ie, urban outreach to a slum population). The input variables consisted of the vaccine delivery cost, split into groups based on type of cost subcomponent and the output variable was the number of children vaccinated in 2019/20 in each district by the vaccine delivery modality.

To evaluate the efficiency of the DMUs, efficiency scores were computed by taking the optimal ratio of the sum of weighted outputs to inputs. They are measured on a scale of 0 to 1, where a value of 0 indicates that the unit is highly inefficient (vaccinating no one), and a value of 1 is that the unit is relatively efficient, in that no other DMU was operating more productively in vaccinating more children with comparable inputs. To demonstrate the differences in efficiencies between the DMUs, three levels of efficiencies/inefficiencies were arbitrarily defined: efficiency scores ranging from 0.95 to 1 are classified as efficient, from 0.7 to 0.95 as inefficient and any score below 0.7 is considered highly inefficient.

Estimating Pakistan's under-5 subpopulations at the district-level by geotype, and extrapolating unit cost estimates to 113 districts

Online supplemental appendix B provides information about the process of estimating the breakdown of Pakistan's under-5 population into subgroups at the district-level, while online supplemental appendix C describes the regression model used to extrapolate the unit cost to the remaining 113 districts of Pakistan.

Allocative efficiency optimisation modelling

Our allocative efficiency analyses were conducted by following the population cohort of simulated live births, factoring population growth with children stratified by key demographics (urban, slum, rural and fragile and mobile groups) and age group (0–11 months and 12–23 months) and identified by their vaccination status (FIC or not FIC). The vaccination interventions estimated in the unit cost substudy target specific population groups in the 0–11 months age bracket (see online supplemental appendix D figure 3).

For a given total budget envelope for the EPI programme in Pakistan, we calculated what the optimal resource allocation mix might be, given the district-specific DMU unit costs. We modelled the corresponding emphases of the various immunisation modalities, to each district and through each delivery model, which is expected to either: (a) maximise the overall vaccine coverage (FIC); or (b) minimise inequity in vaccine coverage between various subpopulations. The equity metric that we used is the Gini coefficient of FIC coverage, a measure ranging between 0 (equity in that every population group has the same FIC coverage) and 1 (maximal inequity). This coefficient is based on the comparison of the cumulative difference in coverage between the subpopulations

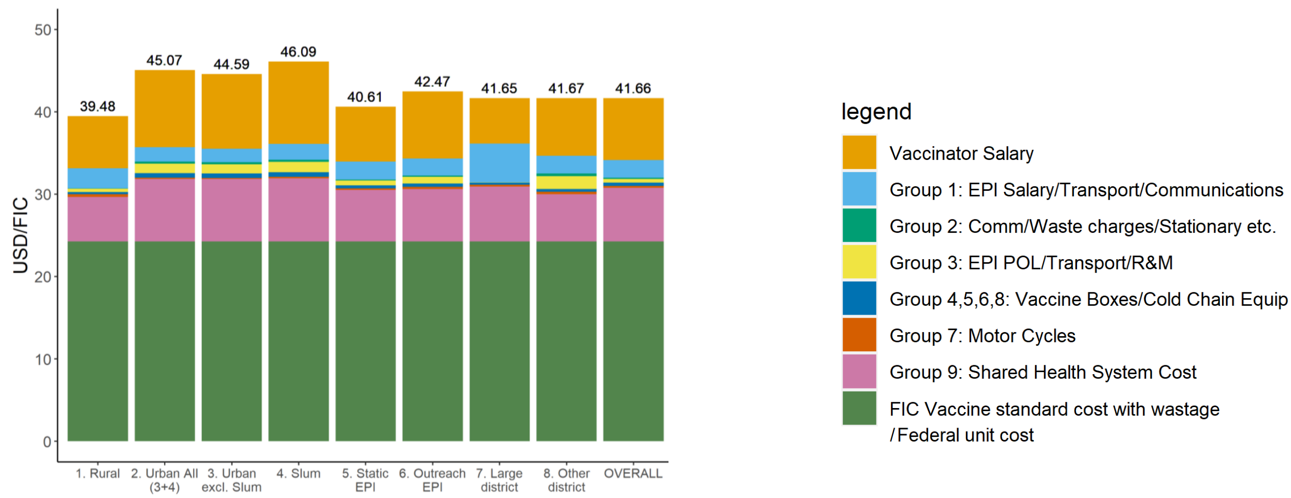

Figure 1 Weighted unit cost by survey domains (USD/FIC). Bars show average unit cost for each delivery mode, averaged over all districts in the sample. EPI, Expanded Programme on Immunisation; FIC, Fully Immunised Children; POL, Petrol Oil Lubricants; R&M, Repair and Maintenance.

against the overall average coverage. We calculated the theoretical optimal allocations at the district and provincial levels, and the results were produced for a range of low-to-high budget envelopes to elucidate the relative prioritisation order of deploying different modalities and strategies for various equity and/or coverage objectives. The optimisation calculations were conducted in Python using an Adaptive Stochastic Descent algorithm.[11]

Patient and public involvement

Study participants or the public were not involved in the design, or conduct, or reporting or dissemination plans of our research.

Reflexivity statement

A structured reflexivity statement is provided in online supplemental appendix S1.

RESULTS

Immunisation services unit cost estimation substudy

Overall, the average weighted cost per FIC in Pakistan was US$42 (figure 1). The FIC unit cost is highest in urban slums (weighted average across urban slums of US$46.09) and lowest in static rural clinics (weighted average across rural clinics of US$39.48). However, weighted unit costs vary from an average of $28.25 per child for the urban fixed domain in Rawalpindi, Punjab, to $88.25 per child for the rural fixed and rural outreach domains in Karachi, Sindh.

Data Envelopment Analysis

Efficiency scores and efficient frontier

There is no pattern of inefficiency by specific delivery modalities, but for a given district all modalities tended to operate either all efficiently or all inefficiently (see figure 2 for the efficient frontier and the efficiency scores of the DMUs). In Balochistan, delivery to all population groups in two of the three sampled districts are very inefficient. The sampled districts in KP were relatively efficient across all modalities and districts except for Mansehra, while Sindh and Punjab had a mix of both efficient and inefficient sampled districts. Of the inefficient and highly inefficient district-modalities (DMUs), 67% are not in provincial capitals or in large districts but in other smaller districts, and Vaccinator Salary and Cost Group 9 amount to 49% and 30% of all excess spending, respectively. Compared with DMUs that have an efficiency score greater than 0.95, on average, inefficient DMUs have higher costs associated with Vaccinator Salary and Cost Groups 3, 4, 5, 6 and 8 while highly inefficient DMUs vaccinated 7591 less children.

In the remaining of this paper, the districts of Lahore (in Punjab), Karachi City (in Sindh), Mansehra (in KP) and Quetta (in Balochistan) are taken as example districts to demonstrate the results from the DEA and optimisation analyses.

Cost components for potential technical efficiencies

For each district's delivery models which are not on the DEA efficiency frontier, we compared the relative cost components of their unit and overall costs with input

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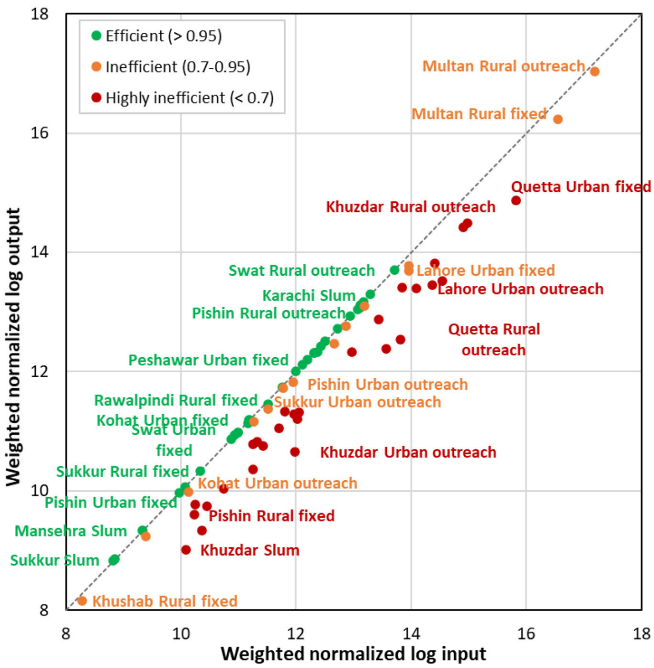

Province	District	Service delivery modality: Rural Fixed	Rural Outreach	Slum	Urban Fixed	Urban Outreach
Punjab	Khushab	0.889	1	1	1	1
	Lahore	-	-	0.503	0.836	0.65
	Layyah	0.527	0.768	0.6	0.555	0.525
	Multan	0.725	0.859	0.623	0.625	0.819
KP	Rawalpindi	0.951	0.956	1	1	1
	Kohat	1	0.98	1	1	0.87
	Mansehra	0.617	0.62	1	0.513	0.861
	Peshawar	0.978	1	1	1	1
	Swat	1	1	-	1	0.974
Balochistan	Khuzdar	0.512	0.616	0.345	0.357	0.267
	Pishin	0.535	0.963	1	1	0.945
	Quetta	0.361	0.282	0.401	0.386	0.306
Sindh	Karachi	0.498	0.494	1	0.917	0.908
	Kashmore	0.882	1	-	1	1
	Sukkur	1	1	1	0.901	0.875
	Umer Kot	0.479	0.573	-	0.41	0.438

Figure 2 Efficient frontier (left) and efficiency scores (right) of DMUs. Efficiency scores are colour-coded by level of efficiency/inefficiency: green represents efficient DMUs, orange inefficient DMUs and red highly inefficient DMUs. DMUs, decision-making units.

components from districts on the efficiency frontier. We found substantial differences between districts and delivery models in each district, suggesting that potential technical efficiency gains should be targeted to the specific delivery service. For example, in Punjab's Lahore, inefficient spending constitutes 60% of total costs, roughly similar across delivery models, with disproportionate transport and communications costs (see online supplemental appendix E figure 4). In contrast, in Sindh's Karachi City, inefficient spending in delivery makes up 37% of total costs, but this ranges from 0% in the slums and 12%–21% in the urban delivery programmes, to ~76% in the two types of rural delivery programmes. Shared health system costs were a significant driver of additional costs for rural programmes in Sindh, along with high costs of vaccinator salaries. In Balochistan's Quetta, inefficient spending was ~73% of total expenditure and this was relatively consistent across all delivery models. In KP's Mansehra, inefficient spending was 45% on average, but ranged from 0% in the slums to 69% in the urban outreach programme, where the largest driver of inefficiency compared with benchmarked programmes was vaccinator salaries, followed by transport and communication expenses.

Allocative efficiency optimisation modelling

Maximising equity or coverage with incremental budgeting in exemplar districts

According to any specific resource allocations to districts, delivery models and targeted programmes, we used our mathematical model to simulate the expected number of FIC attained in each population group and overall, and the Gini coefficient of FIC coverage for the district and province. Using our mathematical optimisation algorithm, we calculated the theoretical optimal resource allocation, and associated programmatic emphases, which could either maximise FIC or minimise inequity between population groups for any given total resource envelope. Therefore, we simulated the theoretical optimal resource allocations (for both FIC and equity) between districts and delivery models for total resource envelopes ranging from \$5 per child per year to \$75 per child, in \$5 increments (see figure 3 for these results for Lahore, Karachi City, Quetta and Mansehra).

Surprisingly, by focusing on the objective of attaining optimal equity, there is not a noticeable loss of impact in FIC. The reduction in FIC is very small (<13% across all simulations). In contrast, when total resource levels are low (as in Pakistan), there is a large difference in equity outcomes between implementation scenarios which focus on equity versus maximising FIC. The greatest differences in optimal programmatic choices and projected outcomes occur when resources are lowest. For example, in the exclusively urban district of Lahore, at \$5 per child per year, if one were to pursue an objective of maximising FIC, then all resources would go to vaccine delivery in fixed urban sites. However, if one were to pursue an objective of maximising equity, then only 15% of the resources would go to urban fixed sites, 37% to urban outreach sites and 48% to delivery among slum populations. According to these different objectives, one could expect FIC to reach very similar levels overall of 13% and 11%, respectively. However, the Gini coefficient

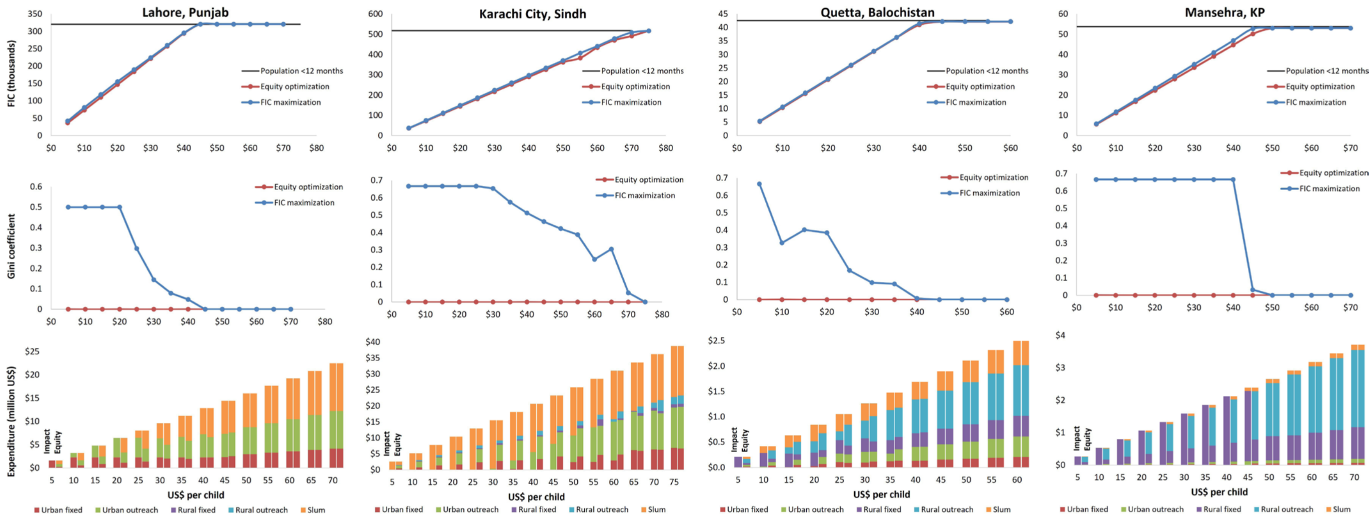

Figure 3 Resource optimisation to maximise FIC or equity in exemplar districts. Top row: number of FIC as a function of health spending per child, middle row: Gini coefficient as a function of health spending per child and bottom row: budget allocation as a function of health spending per child. The y-axis shows the total health expenditure. FIC, Fully Immunised Children.

for equity would be 0.5 and 0, respectively, marking large differences in vaccine coverages between subpopulations across the district. The most significant factor associated with FIC is overall resources in the immunisation programme. If there were $45 per child available for immunisation in Lahore, then FIC would be expected to increase to essentially universal coverage (maximal FIC and also minimising inequity). In this case, the most efficient distribution of resources would be ~18% to urban fixed sites, 34% to urban outreach programmes and 48% to programmes reaching slum populations.

We found similar principles across the other example districts, of (1) similar FIC levels attained when optimising for different objectives but divergent Gini coefficients for low resource amounts; (2) greater convergence of optimal allocations and programming at higher resource levels, but that the optimal programmatic mix differed based on localised unit costs and population distribution. Therefore, it seems evident to us that one should choose the objective which maximises equity because it will also achieve almost maximal FIC.

Our results indicate that at low budget amounts, rural outreach is of importance to improve equity in districts with rural populations. For example, in Karachi City (another almost-exclusively urban district), optimal allocations focus on urban and slum modalities; in the mixed district of Quetta, while resources are limited, priorities should be given to rural and slum areas; and in the highly rural Mansehra, rural outreach and rural fixed modalities are prioritised.

Overall, more investment is needed in Pakistan across all provinces, prioritising rural areas and slums. Reallocations of programme budgets can have an exceptionally significant impact on equity outcomes, particularly at low and moderate spending amounts (<$30 per child). If the budget is over $40 per child, the inequity level quickly drops to zero, meaning EPI can prioritise both FIC impact and equity through the same programming strategy. Considering all things, it is recommended to address equity as the key objective, emphasising rural areas and slums, and the number of FIC will also increase without a large loss of impact.

Technical efficiency gains by optimising unit costs and reinvesting

To highlight the trade-off between FIC coverage and maximum equity in the current and optimised scenarios, FIC (%) was plotted as a function of the Gini coefficient (figure 4) at the current budget of the four example districts. The target on the top left corner of the graphs represents the ideal scenario of maximum coverage (100%) and perfect equity (Gini coefficient of 0).

Improved allocative and technical efficiency with existing resources can result in greater FIC and equity compared with current allocations. For example, in Lahore, current programming in 2019/2020, with ~$6 per child, yielded FIC coverage of ~23% and there was a Gini coefficient of ~0.03 between subpopulations. If the same financial resources were reallocated to optimise for FIC coverage (focusing on fixed urban sites), assuming fungibility of human resources, supply chains, etc, to align with the theoretical optimal, then FIC coverage could increase only very slightly to ~25%, but there would be a large trade-off with a substantial increase in the Gini coefficient to 0.50. In contrast, if the same resources were reallocated towards the objective of maximising equity (mostly splitting resources between urban outreach and slum programmes), then FIC coverage remains at ~23%, but equity between subpopulations could be achieved. The differences between FIC levels in 2019/2020 from recent programming and what could be achieved through different allocation strategies are even less noticeable in Karachi City, Quetta and Mansehra, but through optimising programming for equity, both FIC and equity can be achieved.

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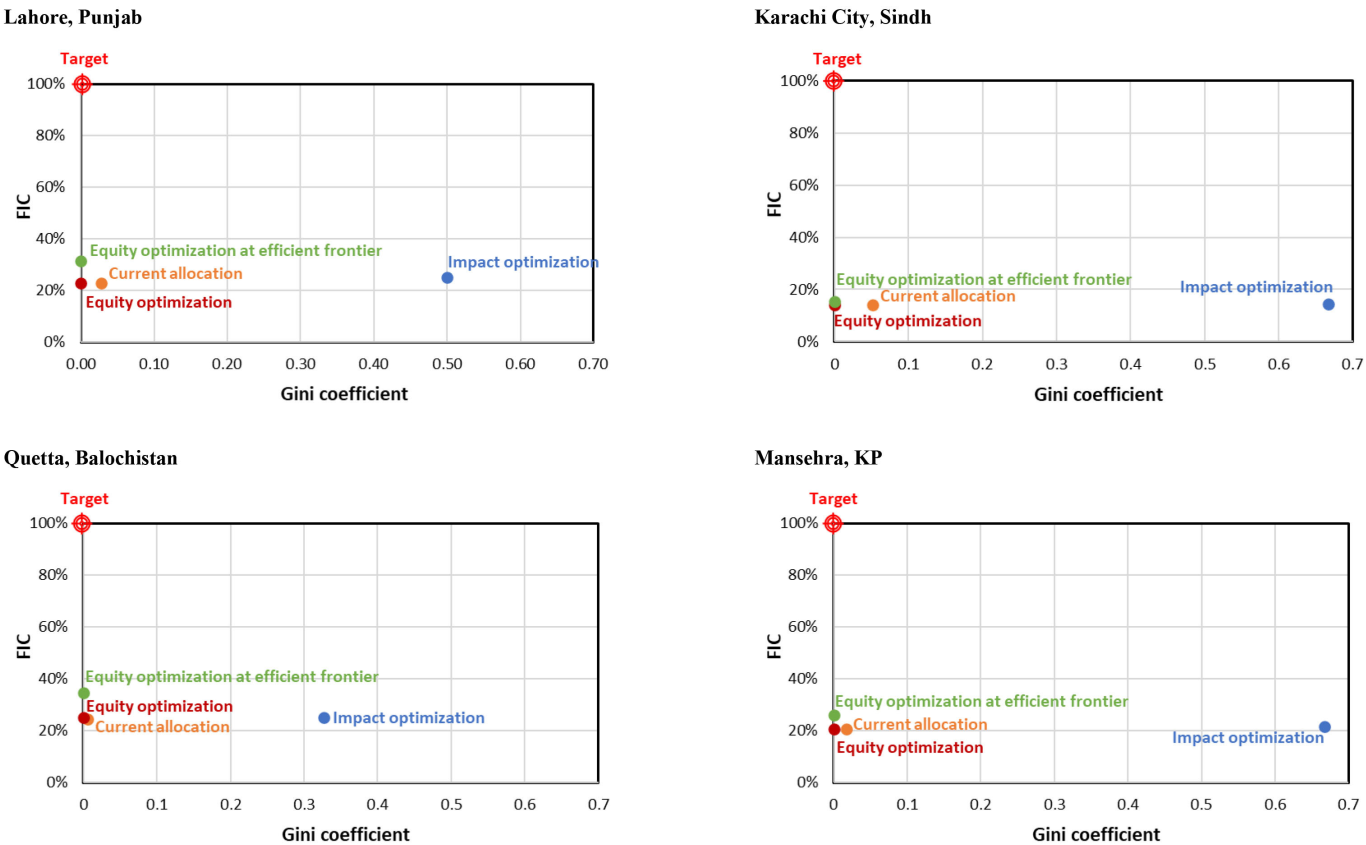

Figure 4 Percentage of FIC (impact objective) versus the Gini coefficient (equity objective) at the current spending level in Lahore, Karachi City, Quetta and Mansehra, for each of the three optimisation scenarios and compared with the current allocation. FIC, Fully Immunised Children.

Some districts had programmes which were benchmarked to be relatively inefficient compared with programmes in other districts. Therefore, we also simulated the potential outcomes in FIC levels if the programmes could run with the technical efficiency deemed possible from the benchmarked efficiency frontier, and if resources were allocated most efficiently for equity. Of our four example districts, Lahore and Quetta had the least efficient programmes. We found that through these efficiency improvements, it would be possible for FIC to increase by ~10%, and to achieve equity between subpopulations. Among our other example districts, improved technical efficiency was simulated to have minimal impact on FIC.

The impact of the reallocation in terms of equity is substantial in all optimisation scenarios (see online supplemental appendix F figure 5). Even more significant is the fact that when the unit costs are optimal, 27 203 more children can be reached by the programmes in urban Lahore (+37% relative to the status quo), 7139 in Karachi City (+10%), 4258 in Quetta (+41%) and 2921 in Mansehra (+26%). In the equity optimisation scenario, compared with the status quo, some of the budget would be reallocated from urban areas to slums in Lahore, and from urban fixed to urban outreach in Karachi City. In Quetta and Mansehra, funding does not need to change substantially: the budget would be slightly reallocated from rural outreach to urban fixed domains in Quetta, and from rural outreach to rural fixed domains in Mansehra. When maximising FIC coverage, the budget is exclusively allocated to one population group (except for Quetta), exacerbating inequity.

Optimised operational planning

Since we conducted ingredients-based costing, we could use this information to define what an optimal allocation would look like, not only in terms of financial resources to each district's service delivery models, but how this would translate to its various ingredients (eg, how many vaccinators, how many vehicles and amount of supply chain equipment). An example of how operational planning can be optimised for equity is shown for Quetta in online supplemental appendix G table 3 and figure 6, at current financial resource levels, as well as if there were more or less funding available. In this example, we assume that the number of vehicles and vaccine boxes would scale roughly linearly with total resources available, however, the distribution of vaccinators between service delivery modalities and locations, non-linearly at lower funding levels.

Geospatial optimisation across districts: example for KP

We also assessed the expected outcomes of FIC levels and equity measure of the Gini coefficient at provincial levels

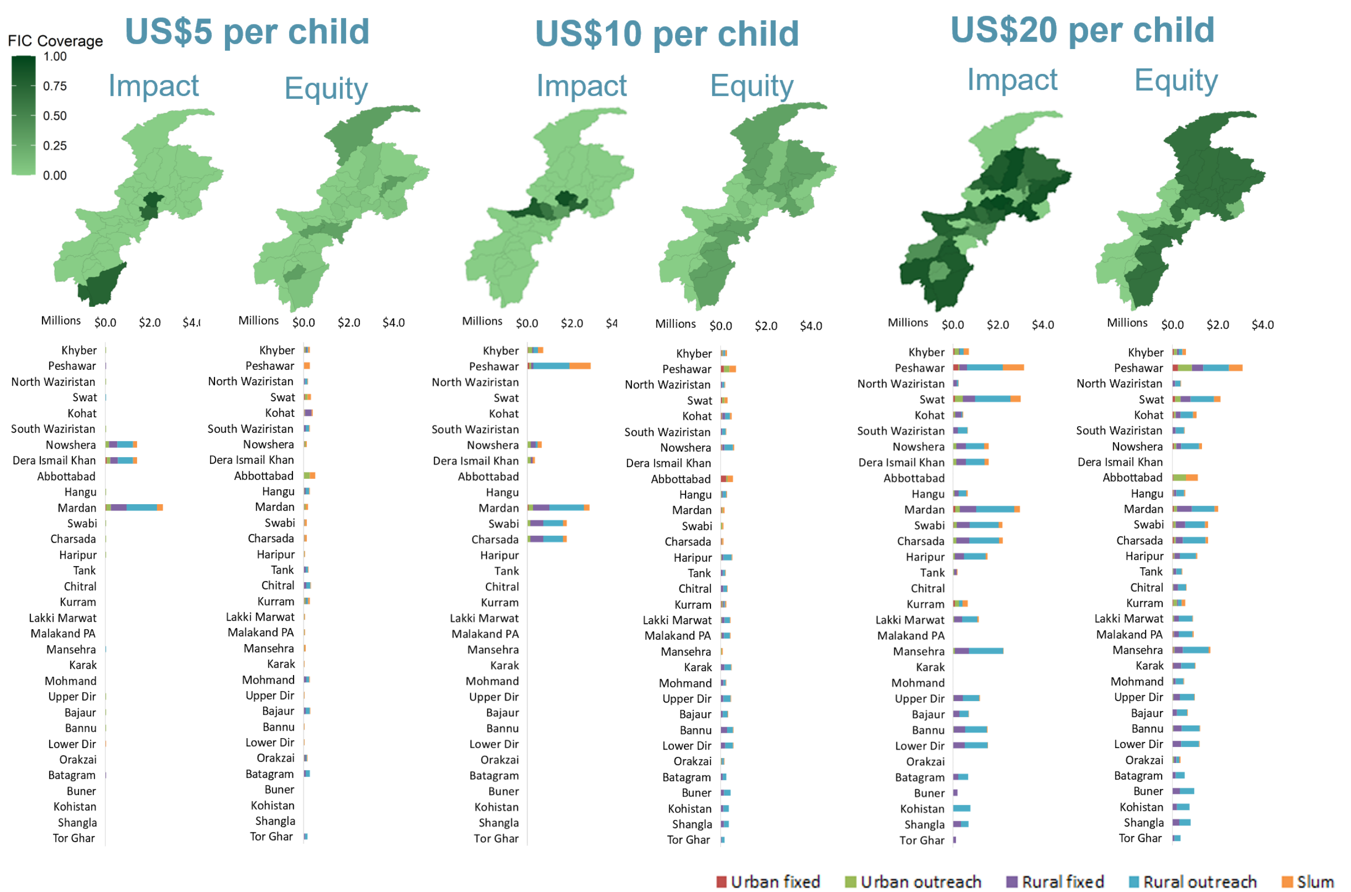

Figure 5 Coverage maps and district-wise budget reallocations of the geospatial optimisations for KP at three budget levels: ~$5, $11 and $22 million. FIC, Fully Immunised Children; KP, Khyber Pakhtunkhwa.

(see figure 5 for the province of KP and online supplemental appendix H for the remaining provinces). The maps depicting FIC coverage and the resource allocation among the districts and by service delivery modalities show a fairer distribution of coverage and funding among districts and modalities when focusing on equity at low budget amounts. At $5 per child per year, of the 32 districts of KP, 25 receive funding when focusing on the equity objective versus 3 when maximising FIC coverage.

In line with the district-based optimisation, provincial rural outreach programmes should be prioritised over urban outreach programmes. The geospatial optimisation at $5–$20 per child per year shows that ~50%–54% of funds should be allocated to rural outreach programmes, and ~25%–27% to rural fixed programmes, irrespective of the optimisation objective.

We did not find a large trade-off in FIC coverage by focusing on equity instead of maximising FIC coverage (the maximum reduction in FIC is <24%, at low budget amounts). Programmatically, optimising for equity versus FIC is similar only at higher resource amounts.

DISCUSSION

In this paper, we generate evidence to guide both efficient and equitable resource deployment of childhood vaccine coverage in Pakistan. Different delivery models are required to reach diverse population subgroups, and since the literature on the costs of fully immunising children through these delivery models in Pakistan was lacking, we conducted a substudy to estimate the annual unit cost of fully immunising a child. The unit cost data were subsequently used to estimate the immunisation coverage levels and equity across various populations associated with different combinations of service delivery modalities and levels of expenditure, and to demonstrate the expected trade-offs between coverage and equity.

Delivery inputs differed between vaccine delivery models. Unit costs from the sampled districts varied from US$28.25 per child for the urban fixed domain in Rawalpindi, Punjab, to US$88.25 per child for the rural fixed and rural outreach domains in Karachi, Sindh. Overall, vaccinator salaries constituted 45.7% of delivery costs and shared health system costs constituted 33.7%. Benchmarking suggests that ~44% of delivery models are running efficiently and 37% are highly inefficient (<70% efficiency), with disproportionately greater inefficiency associated with transport and communication items. From the districts sampled, services were relatively efficient in KP, relatively inefficient in Balochistan and a mix of efficient and inefficient in Sindh and Punjab.

Results from the DEA and optimisation modelling show that if services could be improved to operate at optimal levels, technical efficiency gains can be substantive and can be reinvested for greater impact (figures 3 and 4). In practice, it may not always be possible to achieve technical efficiency gains because some locations will be harder and more expensive to work in due to higher intrinsic costs, lower demand, accessibility or infrastructure. However, even small progress towards more efficient service delivery could have an impact, with areas identified as relatively inefficient possibly drawing insight from their efficient counterparts as to where and how technical efficiency gains might be achieved in practice.

While coverage and equity are usually at odds, surprisingly we found that substantial improvements in equity in coverage levels between subpopulations does not necessarily cost very much in this context: theoretically, it can be achieved while still attaining close to maximal FIC at both the district and provincial levels (see online supplemental appendix F and figure 5). Within each district, unit cost differentials were sufficiently small that reallocating funding to focus on maximising equity did not lead to a large reduction in potential FIC coverage, but could have a significant impact on equity outcomes, particularly at current low spending amounts. In practice, budget line items may not need to change substantially (eg, total number of vaccinators) to maximise FIC coverage or equity, but where and how they are deployed for delivery to specific populations could make a substantive difference. In general, it is more difficult to reduce inequities between districts than inequities between subpopulations within the same district, because the unit cost variation between districts was greater between districts than between delivery models in the same district. Nevertheless, the trade-off between optimising for equity and optimising for FIC showed that at a provincial level, it still did not cost much to achieve equity. Therefore, it is recommended to address equity as the key objective.

Maximising equity could be done by first emphasising districts with greater rural and slum populations and the delivery models which service rural areas and slum populations, before prioritising the most efficient urban areas as greater resources are available. Rural and slum populations are often underserved by existing vaccine programmes, and prioritising communities with high numbers of zero-dose children (defined as children who have not received any routine vaccination or the first dose of diphtheria– tetanus–pertussis containing vaccine (DPTcv1),[12]) is of utmost importance for reducing the number of VPDs and infant and child deaths.

This analysis is even more important in the context of COVID-19, which has increased inequity.[13] Due to the disruptions associated with the pandemic, it is estimated that zero-dose children increased from 13.6 million in 2019 to 17.1 million in 2020, the highest number since 2009.[14] What is most striking is the geographic context behind these data: the lower income countries that are supported by the Gavi Alliance (Pakistan being one of them) were more largely affected than higher income countries, and just 10 low-income and middle-income countries accounted for 62% of all undervaccinated and unvaccinated children in 2020.[14] It has been shown that up to two-thirds of zero-dose children live below the poverty line,[15] that the majority live in communities affected by conflict, forced migration, homelessness and religious or cultural marginalisation and that approximately 67% live within 1 hour of a town/city.[12 16] It is also well known that disadvantaged communities that have no access to vaccination are also systematically less likely to have access to primary care health services.[15 17] On this basis, delivering and scaling immunisation and other basic health services to zero-dose and underimmunised communities will require a targeted and evidence-based approach, tailored to local contexts.[13]

There are a number of limitations to this study. First, contextual factors such as poverty, literacy rate, culture and geographical terrain, which may have an effect on the composition of the unit cost, were not considered in the unit cost estimation substudy. In the technical efficiency analysis, efficiency scores were used as a starting point for comparing the performance of the district-modalities and identifying possible sources of inefficiencies. Given that factors such as geographical spread or population density that may influence transport and communication costs were not considered, and that DEA scores are significantly affected by the selection of inputs and outputs, the sample size, measurement errors and statistical noise,[18 19] conclusions cannot be drawn from the DEA alone. Finally, the allocative efficiency analysis does not consider individual, systems or healthcare provider barriers to immunisation coverage,[20] and assumes that scaling up or down of some service delivery programmes can occur with the same unit costs as currently and that human resources and supply chains can flexibly adjust to shifts in programming approaches.

The proposed strategies would require very strong governance mechanisms within each district and across districts as well as strong management and operational coordination for flexible adjustments. Beyond the existence of this governance and Human Resources for Health Management capacity, there may not be the full autonomy to make these modifications. As we move from analytical insight to use in guidance for operational planning and execution, we are currently in the process of ascertaining how to translate the findings, starting with understanding the autonomy of district health units, tehsils and Primary Care Management Committees of basic health units.

The analysis suggests reallocating FIC in ways which are more economical and allowing additional children to be immunised with the same financial resources, according to a theoretical model based on unit cost data of delivery by different delivery models and assuming that these unit costs are reasonably robust and remain appropriate at different scales. The conclusions of this paper are based on a theoretical analysis driven by empirical cost data and it then assumes that the 'cost functions' scale linearly (ie, the unit cost for delivery remains the same) for each location-delivery modality irrespective of scale. However, the current FIC levels are not used in the calculation of what would be the optimal allocation of resources to maximise theoretical FIC levels or equity levels. Therefore, robustness of FIC estimates should not bias results.

A strength of this work is that extra-budgetary resources were able to be captured in the analysis. This is attributable to the National Immunisation Accounts for which information is collected directly from development partners, EPI provincial offices, WHO and UNICEF. As well, by quantitatively measuring equity with a view to analysing trade-offs between different health outcomes, this paper demonstrates how modelling can effectively demonstrate the impact of targeted interventions on achieving equity and can provide measured advice to policy-makers regarding the implementation process. This approach is a novel contribution in the field of health economic modelling and should be used more broadly in future studies.[20 21]

CONCLUSIONS

The variation in unit costs for different immunisation service delivery models between and within districts mean that there is sufficient scope for strategic use of limited resources. The trade-off between equity and coverage is such that reallocation of resources to maximise equity can still achieve close to maximal FIC, but the converse is not necessarily true when resources are limited. Therefore, maximisation of equity should be a priority, through greater efforts to reach rural and slum populations and to promote the delivery models that service them. Moreover, benchmarking of services could lead to technical efficiency gains that could be reinvested to achieve better outcomes for both equity and FIC coverage.

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Contributors RO, AK and HHP guided this work. RO, with DW, conceived the study. HY and AN carried out the unit cost estimation substudy. DW and NS conceived and designed the optimisation analyses. ES estimated the subpopulations at the district level, and AP and DD developed the Data Envelopment Analysis and allocative efficiency optimisation models. FH conducted the modelling and postprocessing. FH prepared the writing and editing of the manuscript under the supervision of DW. All authors have read, contributed to and approved of the final version of the paper. FH is the guarantor of this work.

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