Are vaccination sites in Bangladesh scale efficient?

Valdmanis V, Walker D, Fox-Rushby JA

V. Valdmanis (PhD), Lecturer in Health Economics, Health Economics and Financing Program (HEFP), London School of Hygiene & Tropical Medicine (LSHTM)

D. Walker (MSc), Research Fellow in Health Economics, HEFP, LSHTM

J. Fox-Rushby (PhD), Senior Lecturer in Health Economics, HEFP, LSHTM

Word count:
Abstract - 136
Text - 3923 (excluding references and tables)

Address for correspondence
V. Valdmanis,
Health Economics and Financing Program,
Health Policy Unit,
Department of Public Health and Policy,
London School of Hygiene & Tropical Medicine,
Keppel Street, London, WC1E 7HT, UK
Email: vivian.valdmanis@LSHTM.ac.uk

Tel +44 207 612 7807
Fax +44 207 637 5391

Abstract

While our understanding of some of the key features of different vaccination programs is becoming increasingly refined, little information has been compiled on the costs of increasing coverage rates. Therefore, it is important to obtain data on the relative scale efficiency of vaccination services, as a first step to assessing appropriate strategies to improve access to vaccination services. To fill this lacuna, we employ Data Envelopment Analysis (DEA) that allows us to compare all the clinics in our sample in terms of input costs utilised in producing multiple outputs. We apply the DEA approach to the Expanded Program on Immunization (EPI) operating in Dhaka City Corporation, Bangladesh during 1999. We found a preponderance of EPI sites operating at increasing returns to scale, thereby questioning the applicability of cost effectiveness analyses that assume constant returns to scale.

Key words: scale, cost, efficiency, immunisation, data envelopment analysis, Bangladesh

Introduction

Compared with other health interventions, vaccinations are judged to be one of the most cost-effective ways of improving and maintaining child health, especially in low-income countries (World Bank, 1993). This view has been held for a considerable time (e.g. Walsh and Warren, 1982) and may help to explain the increase in global coverage of the Expanded Program of Immunisation (EPI) from an average of 5% at its inception in 1974 to an average of 80% (Cutts & Olivé, 1998). It is estimated that this coverage prevents over 3 million child deaths every year (UNICEF, 2002). Today two important policy debates continue within countries and at the international level; whether or not new vaccines should be introduced or not and/or the existing EPI coverage be expanded. The Global Alliance for Vaccines Initiative (GAVI) has already committed hundreds of millions of dollars to questioning and funding both these options.

Many cost and cost-effectiveness analyses of vaccinations in low-income countries have been evaluated by: assuming a given level of production (e.g. Levine et al, 1993); using only a few providers (e.g. Cutts et al, 1990); aggregating and averaging at a country level (e.g. Shepard et al, 1986; Barnum et al. 1980). They tend to report only average costs, with little consideration of the likely marginal cost at that point of production or how costs may change at different levels of production. Therefore little information has been compiled on the costs of increasing coverage rates, or how coverage might be expanded most efficiently.

Even when studies have attempted to estimate the costs of increasing coverage rates or move from a small study to estimating country wide costs, most have assumed a linear function to 'scale-up' programmes (Kumaranayake and Watts, 1999). For example, if the unit cost per

fully vaccinated child is $20, the increase in expanding vaccination services for another 50 children is $1000.

That such constant returns to scale exist is doubted. For example, England et al (2001) have hypothesized that many impediments exist to scaling up measles control in West and Central Africa and that considerable investment will be needed in management and health systems prior to further expansion. They suggested that average costs might rise in reaching the last percentages of population, which might lead to vaccinations becoming less cost-effective relative to other interventions. In reviewing the cost profiles of immunisation programmes from accounting based cost studies, some have found that the proportion of fixed costs indicate the likely existence of economies of scale (e.g. Gilson, 1992). This idea has been supported by Robertson et al (1992), Ugá (1988) and, more recently, by Jian et al (1998), who plotted the average cost per immunisation for each politically administered area in China and drew downward sloping average cost curves.

If average costs and incremental cost-effectiveness ratios do change with production then assuming constant returns to scale will produce biased estimates of any change in production and the bigger the expected change, the larger the bias. Not investigating or accounting for these economic forces can produce biased results that mislead policy, so any global or national predictions of the cost-effectiveness of immunization may need to account for coverage levels. Unfortunately, the quality of evidence is not strong and existing studies suffer from the weakness of not controlling for other potentially influential variables to explain cost or cost-effectiveness (e.g. Berman et al, 1991). Secondly, even if size is accounted for, there is currently no notion of best practice benchmarking (Birch and Gafni, 1992) or knowledge of how this might change by setting.

Asking whether vaccine services are scale efficient is therefore important for a number of reasons. First it offers the chance to question the efficiency of existing services, with a view to recommending the appropriate size of delivery units. This should be important for either of the currently running policy debates. Second, it allows reflection on the accuracy of ranking health interventions by their average and incremental cost-effectiveness ratios in a league table. In this paper, both these issues are informed by a novel application of data envelopment analysis.

The overall aim of this paper is to discern whether and to what degree vaccination sites are not exhibiting constant returns to scale. We pursue three objectives. First, we determine the cost of delivering routine vaccination services from the perspective of the providers (government and non-government, fixed and outreach - defined as a site operating one day or less a week). Second, we assess the outputs of vaccination sites for each provider in terms of the number of doses of diphtheria-pertussis-tetanus (DPT), oral polio vaccine (OPV), Bacillus of Calmette and Guérin (BCG), measles and tetanus toxoid (TT) vaccines administered. We choose ownership as a factor to control for property rights. Third, we determine the scale efficiency of the vaccination sites as well as examine factors that explain variation in scale efficiency.

The Bangladesh EPI and Dhaka City Corporation

The EPI in Bangladesh was established in 1979 and became fully operational in 1985. It aims to reduce morbidity and mortality from six vaccine-preventable diseases: diphtheria, measles, pertussis, poliomyelitis, tetanus and tuberculosis. A fully vaccinated child receives six standard EPI antigens against DPT, tuberculosis, polio, and measles through eight

vaccinations requiring five contacts with health staff: three shots of DPT, three doses of OPV, once shot of BCG against tuberculosis and one shot of a measles vaccine. Pregnant women are given two shots of TT to prevent maternal and neonatal tetanus. Since 1985, vaccination coverage has increased from 2% for all antigens to a reported 92% for BCG and 62% for measles. Because the increase in coverage was achieved first in rural areas, the United States Agency for International Development implemented a program to strengthen vaccination services in urban areas of Bangladesh in 1988.

The delivery of routine EPI services in urban Bangladesh is a complex collaborative effort between municipal governments, the Ministry of Health and Family Welfare, the Ministry of Local Government, Rural Development and Co-operatives, non-governmental organisations (NGOs) and key donors (e.g. the World Bank, Swedish International Development Agency, United Nations Children's Fund and Japanese International Co-operation Agency). However, there is no clear picture of who is accountable to whom. While substantial resources are being used to deliver these services, there seems to be scarce monitoring of the EPI activities.

Dhaka City Corporation (DCC) is the largest of four city corporations in Bangladesh with an estimated population of 5,622,298 in the year 2000 (Bangladesh Bureau of Statistics, 1998). Rapid population growth rate of 6% has resulted in high population density peaking at 300-600 people per acre in the "slum" areas of Dhaka. A survey of facilities providing vaccination services located in DCC showed that 511 facilities provided EPI services (UEP, 1997).

A cost-effectiveness analysis of measles control has been undertaken in DCC (Walker et al, 2000). This showed that the cost per case averted from the measles component of EPI at a 70% coverage rate was $14.4 per discounted life year saved and $11.8 after accounting for

saved treatment costs. This study was based on a stratification of health centres by zone and type of site (fixed or outreach), from which 132 sites were randomly selected representing 25% of the EPI delivery sites. These included 44 (33%) fixed and 88 (67%) outreach delivery sites. Of the fixed sites, 23 (52%) were operated by the government and 21 (48%) by NGOs. Of the outreach sites, only seven (8%) were operated by the government and 81 (92%) by NGOs. Because this data also collected total costs of delivering all EPI activities, it provided an opportunity to assess the efficiency of EPI provision and therefore forms the basis of the data analysed in this paper.

Methods

In this section the model we use to elucidate scale efficiency, and how costs are translated in into our defined set of outputs, is developed. We employ data envelopment analysis (DEA) that allows us to compare all the clinics in our sample in terms of input costs utilised in producing multiple outputs. DEA is a non-parametric, deterministic approach employing linear programming techniques that defines a "best practice" production frontier. Firms lying on the production frontier are considered to be operating at the best practice. In other words, no other firms in the sample are producing the given level of outputs in a less costly manner. However, it should be noted that the measure of efficiency is considered to be relative rather than absolute as we have no a priori information as to what should be considered as absolute efficiency. Therefore, we first propose to assess the clinics in our sample to determine which one(s) is/are producing at relatively the least cost.

A benefit of this DEA approach is that by identifying best practice by a "local" standard, it may be assumed that given certain productive characteristics (as well as environmental ones) best practice can be feasibly reproduced at the less efficient clinics. Another benefit of the

DEA approach used here is that the overall technical efficiency (TECRS) measure can be decomposed into pure technical efficiency (TEVRS) and scale efficiency (SE). In other words, TECRS = TEVRS * SE.

The best practice frontier is constructed by the sampled clinics producing a given level of outputs at the least cost. Whereas there have been a plethora of other related studies applying DEA to the health care sector using inputs in their natural units (see Seiford, 1998 for a review) we specify the objective as minimising input costs given outputs (Färe and Grosskopf, 1985; Färe, Grosskopf and Lovell, 1994). As the objective of this paper is to determine scale effects, the definition of the cost minimising technology used here is applicable.

Whereas the technology is constructed under constant returns to scale and strong disposability of costs (as costs increase, outputs must increase ceteris paribus) allowances can be made in the restraints to allow for variable returns to scale. We first present the linear programming problem used to solve for input cost efficiency under constant returns to scale and than we present the specification to allow for variable returns to scale. In both cases we follow the definitions given by Färe, Grosskopf, and Lovell (1994).

Linear Programming Problem 1: Constant Returns to Scale Technology

$$F_Q(TECRS) = \min \lambda$$

$$\text{s.t.} \quad u^j \leq zM$$

$$\lambda q \geq zQ$$

$$z \in \Re_+^j$$

where Q is total costs, u is the outputs of each clinic "j", M is the matrix of outputs, q is the input costs and z is the intensity variable applied to costs and the outputs.

If a clinic is operating inefficiently under this specification, excess costs are incurred given the outputs produced. If these excess costs could be reallocated elsewhere, than there exists the possibility of potential Pareto efficiency gains.

In order to allow for variable returns to scale, we solve a second linear programming problem (2).

Linear Programming Problem 2: Variable Returns to Scale Technology

$$F_Q(TEVRS) = \min \lambda$$

$$\text{s.t.} \quad u^j \leq zM$$

$$\lambda q \geq zQ$$

$$z \in \Re_+^j$$

$$\sum_{j=1}^{J} z_j = 1$$

The constraint on the z vector in the second linear programming problem allows the data to be enveloped more closely which in turn permits variable returns to scale to be exhibited. If the solutions to the two linear programming problems (LPP) are equivalent than the technology is said to be operating at a cost, as well as scale, efficient level. However, if they are not equal, we can determine to what extent inefficiency is caused due to operating at the

wrong scale. Determining the type of scale inefficiency (either increasing returns to scale versus decreasing returns to scale) requires the solution of a third linear programming problem, referred to as non-increasing returns to scale technology (NIRS).

Linear Programming Problem 3:

$$F_Q(TENIRS) = \min \lambda$$

s.t. $u^j \leq zM$

$\lambda q \geq Q$

$z \in \Re_+^j$

$$\sum_{j=1}^{J} z_j \leq 1$$

In order to define the type of scale inefficiency that is operating here, we compare the solutions of the three linear programming problems. If $\frac{TE^{CRS}}{TE^{VRS}} < 1$; $TE^{CRS} = TE^{NIRS}$ then increasing returns to scale exist. If $\frac{TE^{CRS}}{TE^{VRS}} < 1$; but, $TE^{NIRS} > TE^{CRS}$, then decreasing returns to scale exist. Utilising these models, we can now assess the effects of scale effects on our EPI clinics.

Whereas the benefits of DEA have been enumerated in the health care economics literature including flexible form, the ability to include multiple inputs and outputs, and no requirement to specify a cost or profit function a priori, there have been criticisms levied against this technique. One criticism is that that all deviations from the isoquant are considered

inefficiency rather than statistical "noise". In order to account for the deviations from the isoquant, we propose a two-stage approach wherein we analyse the resulting efficiency scores against an array of independent factors that may affect efficiency but are out of the manager's or policy maker's direct control. Specifically, we analyse the resulting efficiency measures using a variety of statistical tests, in conjunction with other environmental factors that may affect scale efficiency.

Data and Results

In order to be parsimonious, we specified five outputs and one input – total program costs of the EPI by site. The five outputs include the amount of the following type of doses given for DPT, TB, polio, measles and TT in 1999. We only included program sites that did not have missing values. The final data set consisted of 118 program sites. The descriptive statistics are given in Table 1. We find that the average number of OPV doses administered is the most common type of vaccine provided by these sites, whereas the average number of measles doses given is the least regularly provided. In order to adjust the multi-vaccine dosages with single vaccine dosage, we multiplied the total number of doses provided by the percent of those vaccinated that received the full dosage. We also note that, the outputs as well as the total costs are highly skewed.

[Insert Table 1 here]

Turning next to our efficiency results given in Table 2 we find that overall efficiency (TE CRS) is only 0.33. In other words, if program sites were technically efficient and operated at the correct scale, costs could be reduced by 67 per cent without sacrificing the current level

of outputs produced. By decomposing this overall measure into pure technical efficiency (TE VRS) and *Scale* efficiency, we point out that more of the overall inefficiency is due to sites incurring too much cost in producing the array of vaccinations rather than operating at the wrong size. However, both sources of this overall inefficiency must be addressed for these sites to become less wasteful of scarce resources.

[Insert Table 2 here]

As we have demonstrated, the sites in our sample exhibited variable returns to scale. Now we examine the types of diseconomies of scale. Table 3 shows that the majority of the program sites exhibit increasing returns to scale (implying that they are too small), 17 program sites exhibit decreasing returns to scale (implying that they are too large) and only 6 program sites were the "right" size.

[Insert Table 3]

We are also interested in assessing our efficiency results with ownership (governmental versus non-government organizations) status (fixed program sites versus outreach), how long the sites have been in operation, as well as in which zones they operate. Table 4 shows statistically significant differences between the efficiency of two ownership forms, and that scale efficiency is relatively greater in governmentally owned program sites. As outreach sites were statistically significantly less scale efficient than fixed sites, we infer that satellite sites are smaller.

[Insert Table 4 here]

Whilst the EPI program has been in existence in DCC since 1988 not all sites began providing EPI services at the same time. Table 5 shows that the length of time a program site has been in operation is positively correlated with scale efficiency.

[Insert Table 5 here]

One technological problem with providing vaccination services is that whenever a vaccine vial is opened, any unused vaccine in the vial at the end of the vaccination session cannot be stored but must be thrown away. Hence, we are also interested in assessing waste by each site's scale efficiency. For our purposes, vaccine waste is measured by the amount of the vaccine that is discarded divided by the amount that is used. These results are presented in Table 6. We find that sites which exhibited increasing returns to scale also had the highest degree of waste and that the differences among the return to scale types is statistically significant (F-value 11.88, $Pr < 0.0001$).

[Insert Table 6 here]

Discussion

In this paper, we examined the economies of scale for program sites providing vaccines in DCC, Bangladesh. By utilising a DEA approach, we have constructed a best practice frontier from 118 vaccination sites. By relaxing some of the constraints in the model, we are able to discern whether these program sites suffer from increasing or decreasing returns to scale or enjoy practising at constant returns to scale.

We found that the types of vaccines provided varied by clinic. There could be several reasons for this. First, there has been a mass campaign to eradicate polio in Bangladesh since 1995 and therefore more people could be aware of the benefits of polio vaccines and consequently demand these vaccines vis-à-vis the other vaccines available. The measles vaccine, even though the disease is still a serious health threat in the DCC, is not being demanded at the rate of the other vaccines. This may be because it is the last vaccine in the schedule.

The sites in our sample are, on average, relatively inefficient both in terms of technical inefficiency (using too much cost to produce outputs) as well as scale inefficiency (operating at the wrong size). In order to become technically efficient, program sites would have to decrease their costs by 50% and by operating at the right size, costs could have been reduced further by 36%. It also shows that there is considerable room for expansion of EPI provision within existing service settings.

We are also interested in some of the environmental factors that may be affecting scale efficiencies. Sites that were relatively more inefficient, on average, were NGO satellites. Therefore, the governmentally owned sites, perhaps due to more centralised control, were better at long term planning. It suggests that given this source of market failure, government provision of vaccination services does lead to an improvement in efficiency. We also found that sites that had been practising longer were relatively more scale efficient, which is perhaps attributable to a learning curve effect. In addition, we found that sites operating at increasing returns to scale incurred more waste, due to disuse of vaccines in a given period. This suggests that merging the smaller sites would reduce not only excessive costs attributed to scale diseconomies but also reduce the amount of vaccines wasted.

We are aware that our analysis might be further extended and of the potential criticisms of our approach. For example, we might adopt the analysis of expanding output subject to the restriction of inputs and of assessing the impact of differences in input substitution and relative prices, and these analyses are ongoing. We might also have completed the analysis using natural units. With respect to criticisms, we recognise that all deviations from the frontier are treated as inefficiency, effectively discounting the possibility of random error. We also concerned about the impact of not placing the vaccination services in the context of the inputs and outputs of the broader service unit. For example, allowing a certain level of inefficiency in vaccination services may allow sufficient flexibility for a health centre to operate more efficiently. Finally, we recognise that the approach is only relative and that further cost reductions could still be possible beyond the identified frontier.

Nevertheless, given our identification of significant technical inefficiencies and increasing returns to scale in the production of vaccinations in DCC, we consider how this might impact on the interpretation of cost-effectiveness ratios and decisions of how to allocate resources using existing decision rules for cost-effectiveness league tables.

If pure technical inefficiencies exist, then it means that a cost-effectiveness ratio does not reflect the minimum efficient point of production at a given level. Not knowing whether, or the degree to which, a cost-effectiveness ratio incorporates technical inefficiency could have a significant impact on decisions using them. Consider, for example, a more efficient health system incorporating cost-effectiveness ratios of health interventions from a less efficient health system. The cost-effectiveness ratio will be higher than could be expected if the service were provided within their own system and therefore, if the transported ratio is used,

the intervention be less likely to be adopted and hence inefficiencies in one system are imported into another.

Knowledge of the level of pure technical inefficiency could change the type of cost-effectiveness ratios presented. Ideally, this would mean that the minimum efficient cost-effectiveness ratios would be provided. However, it seems to imply that the practices of undertaking cost-effectiveness analyses would need to change. For example, providing cost-effectiveness ratios using costs from a limited number of providers is unlikely to be sufficient, unless relative prices and the marginal rate of technical substitution between inputs are the same. Where treatment practices are expected to vary more across providers, then a larger sample will be needed. This has implications both for sample sizes and the structure of samples for randomised clinical trials as well as approaches taken to modelling where evaluators aim to collect local costs and apply them to effectiveness data.

The presence of increasing returns to scale has other implications. First it means that interventions can't be treated as divisible for a population and retain the same average level of incremental cost-effectiveness. In such a case, Johanesson (1996) suggests that the decision-makers willingness to pay approach for choosing the allocation of health interventions would be more appropriate than maximising outcomes subject to a fixed budget. This is simply because the latter either provides a programme or not, and therefore there is no division of programmes.

Johanesson (1996) also suggests that interventions with increasing returns to scale are presented as 'mutually exclusive' options for each level of production within a league table. However, in the event that increasing returns to scale exist over all levels of production, the

greatest level of production will demonstrate extended dominance over all other options, and therefore all production prior to the minimum efficient point would be excluded. Thus interventions with increasing returns to scale are less likely to be provided but conversely assuming constant returns to scale when increasing returns to scale exist means that interventions are likely to be over provided.

The potential resulting inefficiencies in resource allocation are likely to be exacerbated by the main decision-making approaches to cost-effectiveness that exert particularly restrictive assumptions. Jacobs and Baladi (1996) pointed out that assuming constant returns to scale may not be realistic, and our empirical results support this contention. Whether economies of scale are likely to be exhibited to the same degree in other health services or other health settings is an empirical question. We also note with interest the recent review on learning effects with health technology (Ramsey et al, 2000) and its potential application to understanding economies of scale and cost-effectiveness analysis. However, researching this issue will require larger sample sizes for the resources and costs of providing services than usually underpin cost-effectiveness analyses in practice. Therefore we support recent calls for randomised clinical trials to provide costs from each trial centre (e.g. Coyle and Drummond, 2001, Raikon et al 2000, Wilke et al 1998,) and would encourage the analysis of variation to include analyses of technical and scale efficiency.

We conclude that ignoring the possible existence of technical inefficiencies and variable returns to scale would make generalizability of cost-effectiveness ratios suspect and could lead to a misallocation of resources.

Acknowledgements

We acknowledge and thank Dr Suhaila Kahn at ICDDR'B for her organisation of the data collection in the original cost-effectiveness of measles study and Dr Mahmud Kahn at Johns Hopkins University who was one of the principal investigators on the same study. Vivian Valdmanis, Damian Walker and Julia Fox-Rushby are members of the Health Economics and Financing Program, which is supported by funds from the UK Department for International Development (DFID).

References

1. Bangladesh Bureau of Statistics. *Statistical Pocketbook of Bangladesh, 1997*. BBS, Dhaka. 1998.
2. Barnum HN, Tarantola D, Setiady IF (1980) Cost-effectiveness of an immunization programme in Indonesia *Bulletin of the World Health Organisation* 58, 3, 499-513
3. Berman P, Quinley J, Yusuf B, Anwar S, Mustaini U, Azof A, Iskandar. 1991 et al. Maternal tetanus immunization in Aceh Province, Sumatra: the cost-effectiveness of alternative strategies. *Social Science & Medicine* 33(2): 185-92
4. Birch S, Gafni A. 1992. Cost-effectiveness/utility analysis. Do current decision rules lead us to where we want to be? *Journal of Health Economics*, 11(3): 279-96
5. Coelli, T.J. 1996, "A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program", CEPA Working Paper No. 8/96, ISBN 1 86389 4969, Department of Econometrics, University of New England
6. Coyle D, Drummond M (2001) Analyzing differences in the costs of treatment across centres within economic evaluations *International Journal of Technology Assessment in Health Care*, 17, 2, 155-163

7. Cutts FT, Olivé J-M. 1998. Chapter 44, Vaccination programs in developing countries. In: Plotkin SA, Orenstein WA, eds. *Vaccines*. 3rd ed. Philadelphia: W.B. Saunders Co. pp: 1047-73.
8. Cutts FT, Phillips M, Kortbeek S, Soares A. 1990 Door-to-door canvassing for immunization program acceleration in Mozambique: achievements and costs. *International Journal of Health Services* 20(4): 717-25.
9. England S, Loevinsohn B, Melgaard B, Kou U, Jha P (2001) The evidence base for interventions to reduce mortality from vaccin-preventable diseases in low and middle-income countries *CMH Working Paper Series*, paper no. WG5 10, Commission on Macroeconomics and Health
10. Färe R, Grosskopf S and Lovell CAK. 1994. *Production Functions*. Cambridge: Cambridge University Press.
11. Färe R, Grosskopf S. 1985. A non-parametric cost approach to scale efficiency. *Scandinavian Journal of Economics*. 87(4): 594-604.
12. Fine PEM. 1993. Herd immunity: History, theory, practice. *Epidemiol Rev* **15**:265-302
13. Gilson L 1992 Quality and cost of primary health care in rural Tanzania *PhD Thesis*, London School of Hygiene and Tropical Medicine
14. Jacobs P, Baladi JF. 1996 Biases in cost measurement for economic evaluation studies in health care. *Health Economics*. 1996 5(6): 525-9.
15. Jian et al 1998 Costs of polio immunization days in China: Implications for mass immunisation strategies *International Journal of Health Planning and Management* 13, 5-25
16. Johanesson M (1996) Theory and Methods of Economic Evaluation of Health Care, Kluwer Academic Publishers

17. Kumaranayake, L., Watts, C. 1999 |Costs of scaling up HIV program activities to a national level for sub-Saharan Africa: Methods and Estimates *The South African Journal of Economics* 68 (5) 1012-1032.
18. Levine OS, Ortiz E, Contreras R, Lagos R, Vial P, Misraji A, Ferreccio C, Espioza C, Adlerstein L, Herrera, Casar C. 1993. Cost-benefit analysis for the use of Haemophilus influenzae type b conjugate vaccine in Santiago, Chile. *Am-J-Epidemiol* 137(11): 1221-8.
19. Raikou M, Briggs A, Gray A, McGuire A (2000) Centre-specific or average unit costs in multi-centre studies? Some theory and simulation *Health Economics* 9, 3, 191-198
20. Ramsey CR, Grant AM, Wallace SA, Garthwaite PH, Monk AF, Russell IT, 2000 Assessment of the learning curve in health technologies. A systematic review *International Journal of Technology Assessment in Health Car*e 16(4) 1095-1108
21. Robertson RL, Hall AJ, Crivelli PE, Lowe Y, Inskip HM, Snow SK. (1992) Cost-effectiveness of immunizations: The Gambia revisited. *Health Policy And Planning* 7(2): 111-22
22. Seiford LM. 1998. A bibliography of Data Envelopment Analysis. In: Charnes A, Cooper WW, Lewin AY, Seiford LM, eds. Data Envelopment Analysts: Theory, Methodology and Application. pp: 437-469.
23. Shepard DS, Sanoh L, Coffi E. (1986) Cost-effectiveness of the expanded programme on immunization in the Ivory Coast: a preliminary assessment. *Social Science & Medicine* 22(3): 369-77.
24. UEP. 1997. *An inventory of health and family planning facilities in Dhaka City*. ICDDR,B, Dhaka. 1997.
25. Ugá MAD (1988) Economic analysis of the vaccination strategies adopted in Brazil in 1982 PAHO Bulletin 22(3) 250-268
26. UNICEF. 2002. Website accessed May 2002

27. Walker D, Khan S, Akramazan, Khan M, Fox-Rushby J, Cutts F. (2000) *Cost-Effectiveness of Measles Control in Urban Dhaka, Bangladesh* Final Report to WHO, Geneva
28. Walsh JA, Warren KS (1982) Strategies for Primary Health Care: Technologies for the control of disease in the developing world. The University of Chicago Press, Chicago
29. Willke RJ, Glick HA, Polsky D, Schulman K (1998) Estimating country-specific cost-effectiveness from multinational clinical trials *Health Economics* 7, 6, 481-494
30. World Bank. *World Development Report 1993. Investing in Health*. Oxford: Oxford University Press, 1993.

Table 1: Descriptive Statistics of Outputs and the Inputs

Variable	Mean	Std. Deviation	Min	Max
DPT	257.40	304.94	1	1680
BCG	578.57	685.54	1	3264
Polio	707.42	842.91	1	3756
Measles	190.28	210.83	1	960
TT	390.03	443.37	1	2208
Total Costs	2600.31	4972.79	238	45716

Table 2: Descriptive Statistics of Efficiency Measures

Measure	Mean	Std. Deviation	Min	Max
TE CRS	0.33	0.26	0.001	1.00
TE VRS	0.50	0.29	0.012	1.00
Scale	0.64	0.27	0.007	1.00

Table 3: Returns to scale in vaccination sites

Types of Returns to Scale	Number of Vaccination Sites
Increasing	95
Constant	6
Decreasing	17

Table 4: Selected statistics between ownership and type of clinics and efficiency

	Mean Scale Efficiency Score	F-Test (pr >F)	Median Test (pr >Z)	Kruskal-Wallis (pr > χ^2)
Government	0.77			
NGO	0.60	8.82	2.47	9.77
		(0.003)	(0.01)	(0.002)
Fixed	0.79			
Outreach	0.57	19.73	3.81	17.80
		(0.0001)	(0.0001)	(0.0001)

Table 5: Correlation coefficients for time since EPI clinic opened and total cost and scale

Variables	Correlation Coefficient	Prob > |r|
Time/scale	0.34	(0.0001)
Total Costs/Scale	0.16	(0.08)

Table 6: Returns to scale and vaccine wastage

Returns to Scale Type (N)	Mean Vaccine Waste	F-test (pr > F)	Median one–way (pr > χ^2)	Kruskal-Wallis (pr > χ^2)
IRS (95)	58.58			
CRS (6)	28.01	11.88	12.87	19.52
		(<0.0001)	(0.0016)	(<0.0001)
DRS (17)	31.65			