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ABSTRACT

AIDS is one of the most significant health care problems worldwide. Due to the difficulty and costs involved in treating HIV, preventing infection is of paramount importance in controlling the AIDS epidemic. The main purpose of this paper is to explore the potential of using Data Envelopment Analysis (DEA) to establish international comparisons on the efficiency implementation of HIV prevention programmes. To this effect we use data from 52 low- and middle-income countries regarding the prevention of mother-to-child transmission of HIV. Our results indicate that there is a remarkable variation in efficiency of prevention services across nations, suggesting that a better use of resources could lead to more and improved services, and ultimately, prevent the infection of thousands of children. These results also demonstrate the potential strategic role of DEA for the efficient and effective planning of scarce resources to fight the epidemic.

Keywords: HIV Prevention, DEA, Mother-to-Child HIV Transmission.

JEL Classification: C14, I12

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1. Introduction

The epidemic caused by the human immunodeficiency virus (HIV) is currently one of the greatest public health problems worldwide. It is estimated that in 2009 alone, 33.3 million people were living with HIV/AIDS, 2.6 million were newly infected with HIV and 1.8 million died from AIDS [1]. Although the majority of the disease burden remains in sub-Saharan Africa, the number of HIV-infected people is rapidly increasing in other regions, especially in Eastern Europe and Central Asia.

Due to the difficulty and costs involved in treating HIV, preventing infection is of paramount importance in controlling the AIDS epidemic. In particular, effective prevention measures can reduce new infections, the incidence of the disease and, consequently, the number of people that will require treatment. Whilst appropriate prevention measures can change the course of the epidemic, they require very substantial amounts of resources. It is estimated that the average cost of preventing an infection is US $3,923 [2]. Given the limited resources available to healthcare systems in many of the most affected countries, the implementation of efficient and effective HIV prevention interventions is vital for policy makers and health care managers. It is therefore imperative to identify the most effective HIV prevention strategies as well as the most efficient ways of allocating the scarce resources available to these strategies.

Resource allocation models have been developed over the years intended to inform on allocation strategies that might improve the overall effectiveness of HIV prevention efforts. For some recent examples, the reader is referred to Lasry et al. [3], Earnshaw et al. [4] and Brandeau et al. [5]. However, as pointed out by Rauner and Brandeau [6], determining how best to spend limited resources on HIV prevention programmes in different regions of the world is a challenging task. One way of overcoming this challenge and obtain useful information for decision making consists of identifying best practices that can be shared to promote improvements. Benchmarking exercises to identify best practices amongst health care providers within a country or across countries have the potential to provide essential information for an improved allocation of HIV prevention funds.

The identification of best practice is not, however, straightforward. Although some international comparisons have been carried out in recent years to do so, the approaches adopted have tended to rely on two major types of analysis: one that focuses on specific interventions and compares the relative costs and benefits of a particular prevention programme against the other alternatives (e.g. Beck and Miner [7]; Harling et al. [8]), and another that focuses on data aggregated at the country level and uses multiple performance indicators to show the progress that is being made by each country towards HIV prevention (e.g. UNAIDS [1]). Whilst valuable, these approaches present limitations in carrying out comparative analyses and in identifying best practice. The former is strongly impacted by the range of prevention strategies and geographic settings examined, ignoring the fact that one intervention might not be efficient in some countries but be efficient in others. The latter does not usually account for the fact that some countries might be better than others according to certain indicators, while poorer according to others, making it difficult to derive a single aggregate measure of the overall performance of each of these countries in fighting the HIV epidemic.

The main purpose of this paper is to address these limitations by exploring the potential of using Data Envelopment Analysis (DEA) to establish international comparisons on the efficiency of HIV prevention, focusing on mother-to-child transmission, which is one of the strategies given high priority in battling the HIV epidemic. For an overview of the most important types of HIV/AIDS prevention and treatment interventions, the reader is referred to Rauner and Brandeau [6]. Mother-to-child transmission occurs when an HIV positive woman passes the virus to her baby during pregnancy, labour and delivery, or by breastfeeding. It is estimated that without appropriate prevention and treatment, around 15 to 30 percent of babies born to HIV positive women will contract HIV during pregnancy and delivery. A further 5 to 20 percent will become infected through breastfeeding [9]. It is, therefore, fundamental to ensure that mother-to-child-transmission interventions which counsel and test pregnant women for HIV, offer antiretroviral medications to both the mother and infant to prevent HIV transmission, and often provide substitute feeding programmes to prevent transmission through breastfeeding, are as efficient and effective as possible. An efficient and effective use of resources in this particular context has the potential to save the lives of thousands of children each year.

2. Assessing Efficiency of Mother-to-Child HIV Prevention

In recent years, we have witnessed remarkable progress in the fight against the mother-to-child transmission of HIV, with the AIDS Annual Report [1] documenting a significant decrease in the infection rates among children born to mothers living with HIV. According to this report, in 2009, an estimated 370,000 children contracted HIV during the perinatal and breastfeeding period, down from 500,000 in 2001. Mother-to-child HIV prevention has played a key role in this decrease. Unfortunately, however, this success has not been shared to the same extent by all countries. Whilst in high-income countries mother-to-child HIV transmission has been virtually eliminated thanks to effective prevention and care, the number of children infected in low- and middle-income countries is still very high. This might be explained in part by the fact that coverage of antenatal care services and other services for preventing mother-to-child transmission among women living with HIV varies considerably across nations. However, the fact that infection rates also vary considerably among low- and middle-income countries, seems to indicate that the resources allocated to prevention have been more efficiently and effectively used in some countries than in others.

The need to use the resources allocated to HIV prevention efficiently can hardly be overstated. As emphasised by Appleby and Thomas [10] and Flessa [11], an inefficient use of resources in the health care context means not only that money is wasted, but more importantly that the opportunity is lost to save lives, avert pain, and provide care to those in need. The search for efficiency and effectiveness in the use of resources has been a key driving force for many of the OR/MS science applications in the health care sector and for the emergence of important publications in this area (see, for example, Ozcan and Smith [12]).

Simultaneously with this call for more efficiency and effectiveness in health care, a call for a further shift in the balance between prevention and treatment has also been spread, with some authors acknowledging that OR/MS techniques have an important role to play in helping this shift towards more prevention (e.g. Royston [13]). While these calls apply to all health care areas, they are particularly meaningful in the case of the HIV/AIDS epidemic. The Committee on HIV Prevention Strategies in the United States pointed out that decisions regarding the allocation of HIV prevention funds represent the single most important set of HIV prevention decisions made [14]. However, as emphasised by Kaplan and Merson [15: 1907] it is important to bear in mind that HIV "resource allocation is not simply an argument for how to divide the pie; some allocations are arguably better than others."

Considering that an efficient and effective allocation of resources is a key ingredient in controlling the HIV epidemic, and that there is some compelling evidence suggesting that the unit cost of HIV prevention programmes may be both higher and more variable than some estimates suggest (e.g. Marseille et al. [16]), it is fundamental for researchers to carry out comparative analyses across nations in order to identify best practice. The research we discuss in this paper aims to shed some light on this issue by comparing the resources spent on mother-to-child HIV prevention by several countries with the services provided.

Although there is an increasing and highly relevant body of literature on the efficiency and/or effectiveness of specific prevention, treatments and care programmes (see for example, Harling et al. [8]), the number of studies assessing and comparing how efficiently different countries are using the available funds to combat the epidemic are very rare. Furthermore, when comparisons are made, these tend to rely on the use of multiple performance indicators or ratios rather than on the use of a single aggregate measure of the overall performance of each country. This problem could be addressed if it was possible to reach an agreement on the relative importance of the various performance indicators. This is, however, seldom the case as the importance of each indicator is dependent upon the perspective taken and upon the priorities of the countries under evaluation.

Data envelopment analysis, developed by Charnes, Cooper and Rhodes in 1978 [17] is a non-parametric linear programming technique which has proved very effective in addressing this limitation and it is one of the most important and widely used approaches to measure the performance of homogeneous decision making units (DMUs) performing the same task. This technique uses a production metaphor. It considers that each DMU is engaged in a transformation process, where by using some inputs (resources) it is trying to produce some outputs (goods or services). With the provision of these services, the DMU intends to achieve certain outcomes, which measure the impact of the services on the users. One of the interesting features of DEA is that it allows each unit to identify a benchmarking group; that is, a group of units that are following the same objectives and priorities, but performing better. In this respect DEA aims to respect the priorities of each DMU by allowing each one of them to choose the weight structure for inputs and outputs that most benefits its evaluation. As a result, it aims to classify each unit in the best possible light in comparison to the other units.

The formulation of the DEA problem, under variable returns to scale, with output orientation, for DMU 0, as proposed by Banker et al. [18] is as follows:

$$Max \quad \phi$$

Subject to:

$$\sum_{j=1}^{n} X_{ij}\lambda_j \leq X_{i0} \qquad (i = 1,\ldots,m)$$

$$\sum_{j=1}^{n} Y_{rj}\lambda_j \geq \phi Y_{j0} \qquad (r = 1,\ldots,s)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \quad (j = 1,\ldots,n)$$

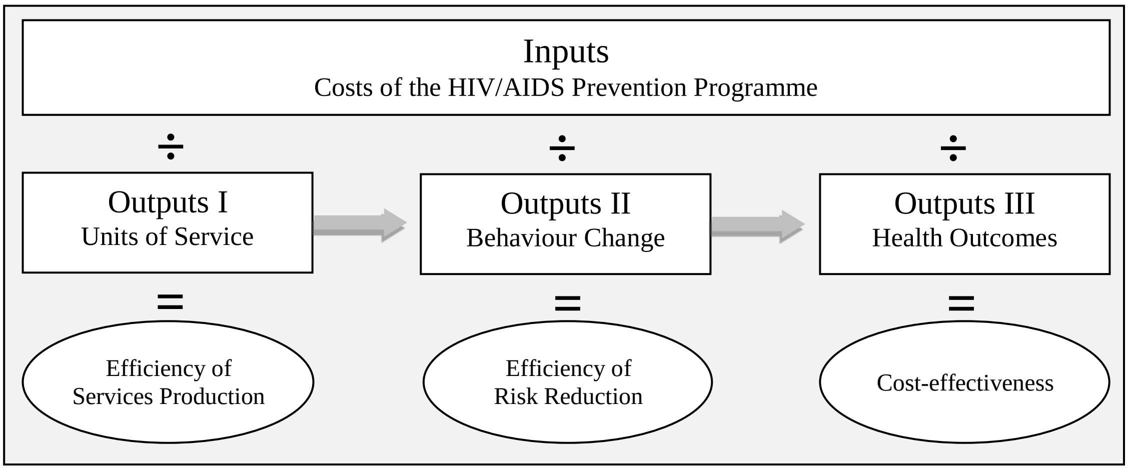
In this problem, n is the number of DMUs; s is the number of outputs and m is the number of inputs; Y_{r0} is the amount of output r generated by unit 0 and X_{i0} is the amount of input i used by unit 0; λ_j is the intensity variable for DMU j. In case the restriction $\sum_{j=1}^{n}\lambda_j = 1$ is not included in the formulation above, the model assumes a constant returns to scale (CRS) technology. The score ϕ obtained from the solution to this linear programming problem is the maximum rate of proportional expansion in all outputs of DMU *0*, without decreasing its inputs. The efficiency rate of DMU *0* can be obtained by calculating 1/ ϕ , and will be equal to 1 if the DMU is efficient, and smaller than 1 if the DMU is inefficient when compared with the other DMUs. A comprehensive review of the DEA technique can be found in Cooper et al. [19, 20].

Since its advent in 1978, this method has been the subject of several theoretical developments and has been extensively applied in many sectors including education, finance, agriculture, sports, marketing and manufacturing, to name just a few. There have also been several documented applications of DEA in the health care sector. The Health Care Management Science Journal, amongst others, has been an important forum for the dissemination of these applications. In two recent special issues of this journal dedicated to contemporary health care applications in OR/MS and to operational research applied to health services, the reader can find several good examples showing the use of DEA in this context (e.g. Ozgen and Ozcan [21]; O'Neill and Dexter [22]; and Langabeer and Ozcan [23]). Hollingsworth et al. [24], Hollingsworth [25], Chilingerian and Sherman [26] and more recently Hollingsworth [27], review several of the DEA applications in the health care context.

Whilst the use of DEA in the health care sector has been prolific, to the best of our knowledge, no studies have been documented on the use of DEA to compare the efficiency of countries in using HIV prevention resources. The only exception in this area is the study by Zanakis et al. [28], which examines the impact of major socio-economic factors on HIV/AIDS indicators and assesses each country's efficiency in battling the epidemic. In so doing, this study makes an important contribution in this under researched area, not only because it is the first one using DEA to assess the efficiency of nations in battling HIV but also because it points out that research on HIV/AIDS should include both individual and social-economic factors, to better understand the development of the global epidemic.

The research we discuss in this paper presents, however, some important departures from Zanakis et al.'s study. Firstly, the assessment of each country's efficiency in preventing HIV infections is the main focus and objective of our research. In Zanakis et al.'s study this objective was part of a broader agenda and played a fairly marginal role. Secondly, our study focuses exclusively on the efficiency of HIV prevention, whilst theirs does not seem to distinguish prevention from treatment. However, our study, in line with the findings reported by Beck [29] and Piot et al. [30] acknowledges that the containment of the HIV epidemic requires a global strategy which combines effective prevention with treatment and care programmes. This implies that some variables related to HIV treatment and care will be considered in the analysis as they have a significant impact on HIV transmission. Thirdly, the model we propose is considerably different from the one they have used. In particular, we focus on a particular programme and use variables more directly related with HIV prevention than the surrogate general health variables used by Zanakis and colleagues. Finally, our study, by using data for 2008, aims to offer an updated overview of the efficiency of recent efforts in battling the epidemic as the analysis carried out by Zanakis et al. used data from 1998. By doing this, our research complements this previous work and makes an important contribution to knowledge. Zanakis et al. recognised that their study was preliminary and that further additional multi-country studies in global efficient strategies for combating HIV/AIDS were needed. As emphasised by Harling et al. [8], establishing multi-country comparative analyses on the use, cost and outcome of HIV prevention services, especially in middle and lower income countries, is critical to fill some of the large gaps which exist in the scientific literature on HIV interventions in these countries. These gaps have limited the ability for the existing literature to guide policy makers in those settings where the epidemic is most intense. As pointed out by Harling et al. [8: 372] "increased research in such settings and dissemination of their findings is urgently required, especially given the need for intensified prevention strategies to complement the scaling up of HIV treatment and care services in these countries."

The framework we propose to assess the efficiency of mother-to-child HIV prevention and in this way contribute to the extant literature, draws on the principles of the Prevent AIDS Network for Cost-Effectiveness Analysis (PANCEA) approach [16]. PANCEA is a five-country study, funded by the U.S. National Institute of Health, aimed at providing information for an improved allocation of HIV prevention funds in low- and middle-income countries. In particular, the PANCEA approach is designed to generate three indicators of efficiency for each prevention programme: cost per unit of service provided, cost per reduction in risky behaviours, and cost per HIV infection prevented. Figure 1 illustrates how these indicators build on each other.



Source: Adapted from Marseille et al. [16].

Figure 1. The PANCEA Conceptual Framework

The first indicator of efficiency measures the cost per unit of service provided by a particular programme or intervention (e.g. cost per pregnant woman who received voluntary counselling and testing). The second indicator of efficiency assesses the cost of reducing risky behaviours (e.g. cost per newly protected sex episode). The third indicator measures the cost effectiveness of the programme by comparing its costs with the outcomes achieved (e.g. cost per HIV infection averted).

The analysis we discuss in this paper focuses essentially on the Efficiency of Services Provision regarding mother-to-child HIV prevention. In spite of its limited scope, it can provide essential information for an improved allocation of HIV prevention funds as there is compelling evidence showing that the three indicators above are strongly linked. In particular, behavioural evaluations have shown that the more units of service are provided the lower the risky behaviours tend to be. Epidemic modelling has shown, in turn, that reduction in behavioural risk contributes to reduce HIV transmission. Therefore, it seems reasonable to assume that by comparing the efficiency of service provision across countries and identifying the best performers, we are able to identify those countries that are most likely using the resources in a more effective way. This is, however, the subject of further research. Considering that our study focuses on the efficiency of nations in implementing a particular prevention programme whilst the PANCEA project focuses on the efficiency of particular programmes when compared with alternative interventions, we believe that these two types of approaches can together provide a richer understanding of efficiency in HIV prevention and, consequently, a better foundation for policy recommendations.

3. Empirical Analysis

3.1. The DEA Model

The choice of appropriate input and output variables is a fundamental step in DEA analysis. Whilst several input indicators can be used in this context, the costs of running mother-to-child HIV prevention interventions is, perhaps, the most relevant. These costs are usually grouped into three major categories: personnel expenses (e.g. salaries and other compensation paid to the personnel involved in the prevention programme), other recurrent goods and services expenses (e.g. medicines, laboratory tests, supplies, office and administrative expenses, and utilities), and capital expenses (e.g. medical equipment, furniture, vehicles, computers, and buildings). In this research we use the variable "Prevention of mother-to-child HIV transmission domestic spending from public and international financing sources (US$)" as the only controllable input.

The resources allocated to preventing mother-to-child HIV transmission can have several uses as various interventions are usually developed as part of the core response to achieve this objective. The choice of the most appropriate outputs should, therefore, aim to include in the DEA model those outputs thought to have the greatest potential to reduce mother-to-child HIV transmission. Taking into account this principle, the model we propose has four main outputs.

The first output variable in our model is the "Reported number of pregnant women tested for HIV". As pointed out by the Joint United Nations Programme on HIV/AIDS [31] voluntary counseling and testing are an essential part of any prevention of a mother-to-child transmission strategy. HIV testing is critical because pregnant women who do not know they are HIV positive cannot benefit from appropriate prevention interventions. Considering that the protective benefit of antiretroviral drugs is diminished when babies continue to be exposed to HIV through breastfeeding, HIV positive mothers are advised not to breastfeed whenever they have safe, affordable alternatives to breastfeeding. HIV testing and counseling offer significant opportunities to provide important advice to HIV positive mothers on the risk and benefits of different infant feed options allowing them to make better informed decisions about the most suitable options and, ultimately, contributing to lower mother-to-child HIV transmission. In addition, when testing is carried out and post-testing counseling is given, valuable information and support is also passed to women not infected in order to avoid future infection. Unless the measures we discuss bellow (and which are captured by the other three output variables) are backed up by effective HIV testing and counseling programmes, their full potential to save babies' lives will not be achieved.

The second output variable accounts for the "Number of pregnant women living with HIV who received antiretrovirals for preventing mother-to-child transmission". The administration of antiretroviral drugs to pregnant women decreases the viral load in the mother and is highly effective at preventing mother-to-child transmission (see, for example, Bryson [32]). Pregnant women who are HIV positive are usually advised to begin antiretroviral treatment either immediately or after the first trimester. Under the 2010 World Health Organization guidelines, all HIV positive mothers, identified during pregnancy, should receive an extensive course of antiretroviral drugs to prevent mother-to-child transmission.

In order to lower the risk of transmission even further and/or reduce HIV-related morbidity and mortality, it is important, that newborn babies who have been exposed to the virus, are also given a course of prophylactic treatment for the first few days or weeks with antiretrovirals and/or co-trimoxazole, respectively. Co-trimoxazole is a widely available antibiotic that substantially reduces HIV-related morbidity and mortality in both adults and children. As pointed out by Zachariah et al. [33: 686], "prophylaxis with co-trimoxazole is a recommended intervention of proven benefit that could serve not only as an initial step towards improving paediatric care in young children with limited access to antiretroviral treatment, but also as an important complement to antiretroviral therapy in resource-limited settings". Marseille et al. [34] have also, more than a decade ago, provided evidence suggesting that the administration of antiretrovirals to mothers and babies just before and soon after birth has a major potential impact on reducing vertical HIV transmission. In order to account for these factors, we included in our DEA model the following output variables: "Reported number of infants born to women living with HIV receiving antiretrovirals for preventing mother-to-child transmission" (i.e. Output 3) and "Reported number of infants born to women living with HIV receiving co-trimoxazole prophylaxis within two months of birth" (i.e. Output 4).

In carrying out a comparative analysis of countries in battling the HIV/AIDS epidemic it is also important to bear in mind that there are socio-economic factors (i.e. exogenous conditions) that are not directly controllable by the prevention authorities but can explain differences in efficiency and ultimately help understand the development of the epidemic in each country. Consequently, it is important to include in the analysis nondiscretionary variables (inputs and/or outputs) that will assure comparable technologies. According to Quinn [35], to control AIDS, countries must not only promote changes in individual behaviour but also address socio-economic issues. In fact, considerable HIV/AIDS differences among nations have been attributed to exogenous conditions like nation's wealth, migration from rural to urban areas, education, access to health services and drug use. For example, Zanakis et al. [28], in exploring the effects that socio-economic factors have on the development of the HIV/AIDS epidemic, found evidence that countries with lower population density that manage to provide better health system performance and per capita support with not necessarily higher GNP and better media information are more likely to exhibit lower HIV/AIDS indicators.

In the particular case under analysis, it is acknowledged that good quality HIV/AIDS education is fundamental to eliminate myths and misunderstandings, and to counter stigma and discrimination against pregnant women. It is likely that in countries with lower literacy rates, pregnant women will be less willing to carry out voluntary testing and counseling for HIV, which might result in poorer efficiency results when compared with nations with higher literacy rates. In order to account for this non-controllable factor, and allow fairer comparisons, we decided to include a proxy variable to capture the level of education in the population. We have used the variable "Number of people aged 15 years and older who can, with understanding, both read and write a short simple statement on their everyday life". This variable resulted from the product of the literacy rate of each country and the respective population aged 15 years and older.

In summary, the DEA model we propose to assess the efficiency of mother-to-child-HIV transmission interventions and which was developed based on the literature review and on the discussion presented above, is the one presented in Table 1:

Table 1: DEA model to assess efficiency of mother-to-child HIV transmission prevention

Inputs	Outputs
• ***Input 1***: Prevention of mother-to-child HIV transmission domestic spending from public and international financing sources; • ***Input 2***: Number of people aged 15 years and older who can, with understanding, both read and write a short simple statement on their everyday life.	• ***Output 1***: Reported number of pregnant women tested for HIV; • ***Output 2***: Number of pregnant women living with HIV who received antiretrovirals for preventing mother-to-child transmission; • ***Output 3***: Reported number of infants born to women living with HIV receiving antiretrovirals for preventing mother-to-child transmission; • ***Output 4***: Reported number of infants born to women living with HIV receiving co-trimoxazole prophylaxis within two months of birth.

3.2. Data and Efficiency Results

The data used in this study refers to the activity of 52 low- and middle-income countries regarding mother-to-child HIV prevention in 2008. These countries belong to various geographic regions. In particular, our sample included 27 countries from sub-Saharan Africa, 6 from East, South and South-East Asia, 9 from Europe and Central Asia and 10 from Latin America and the Caribbean.

Data were collected from a variety of international public sources including the Joint United Nations Program for HIV/AIDS, United Nations Development

Program and World Health Organization. Table 2 presents a descriptive summary of the data for the 52 countries considered in the analysis.

Table 2 - Summary statistics for the variables used in the study

	Input 1	Input 2	Output 1	Output 2	Output 3	Output 4
Average	2665009	29742334	350066	5247	4008	1322
St Dev	4928659	81269484	686742	11411	8366	3479
Max	29332921	550995518	4234401	59601	41253	21841
Min	1035	84288	5335	6	0	0

From this table, one can see that there are considerable discrepancies across countries. For example, whilst the average spending on prevention of mother-to-child HIV transmission is approximately 2.7 million US$ per country, some have spent considerably more than others. For instance, Sao Tome and Principe reports the lowest annual spending on this prevention programme (1035 US$), whilst Kenya the highest (29.3 million US$). From another side, we can see that the estimated number of people aged 15 years and older who can, with understanding, both read and write is also highly variable between nations. This is explained in part by the fact that some countries like India are highly populated compared to other, small, countries (e.g. Sao Tome and Principle). Considering that there are remarkable discrepancies at the level of the inputs, it is not surprising that these will also exist at the level of the outputs. As shown in Table 2, the number of pregnant women tested for HIV and the number found to be HIV-positive and receiving antiretrovirals for preventing mother-to-child transmission also varies considerably among the 52 nations on our sample. The same applies to the number of infants receiving antiretrovirals and/or co-trimoxazole. In this particular case, it is important to mention that the zero value, shown as the minimum, indicates that the countries are not providing these medicines to infants or, most likely, that data were not reported, and therefore, it was assumed as being zero. Considering that the model has four outputs and no weight restrictions are imposed on the outputs, we believe that the results obtained with the DEA analysis will not be considerably affected by this assumption.

In order to assess each nation's efficiency, we have used the PIM DEA software [36] and a DEA model with output orientation. This is justified by reasoning that countries should aim to increase the level of service provision, given the spending and the population education. Furthermore, we have used an assumption of variable returns to scale (VRS), as proposed by Banker et al. [18]. According to Marseille et al. [37] the assumption of constant unit costs may result in substantial inaccuracies as they found compelling evidence that efficiency increased (unit costs decreased) with scale, across all countries and interventions examined. Brandeau et al. [5] and Brandeau and Zaric [38], also discuss the issue of scale in HIV prevention programmes, pointing out that the relationship between investment on HIV prevention and HIV infections averted may not be linear, which indicates that increased spending on a prevention programme may not always be cost effective. We have also used a weight restriction on the input side, in order to prevent countries from attributing a null weight to the variable related to spending. This restriction imposes that the virtual weight given by each country to the non-controllable input (i.e. number of people aged 15 years and older who can, with understanding, both read and write a short simple statement on their everyday life) cannot exceed the virtual weight given to the controllable input (i.e. prevention of mother-to-child HIV transmission domestic spending from public and international financing sources). The development of this virtual weight restriction follows the approach proposed by Sarrico and Dyson [39].

Table 3 presents the preliminary results from the DEA model discussed above. It presents the efficiency scores for each one of the 52 countries during 2008 as well as the returns to scale for each country.

Table 3: Countries efficiency scores for 2008

	Technical Efficiency (%)	**Pure Technical Efficiency (%)**	**Scale Efficiency (%)**	**Returns to Scale**
Angola	19.95	35.86	55.63	DRS
Argentina	16.01	58.35	27.44	DRS
Armenia	14.43	26.23	55.01	DRS
Azerbaijan	19.98	61.45	32.51	DRS
Belarus	14.89	47.2	31.55	DRS
Benin	68.67	83.61	82.13	DRS
Bolivia (Plurinational State of)	6.12	16.79	36.45	DRS
Botswana	100	100	100.00	CRS
Brazil	20.25	100	20.25	DRS
Burkina Faso	57.68	83.89	68.76	DRS
Burundi	23.07	23.22	99.35	IRS
Cambodia	15.08	32.77	46.02	DRS
Cameroon	100	100	100.00	CRS
Central African Republic	72.62	74.32	97.71	IRS
Chad	17.11	17.31	98.84	IRS
Chile	7.39	26.65	27.73	DRS
Colombia	8.07	34.72	23.24	DRS
Congo	17.49	18.35	95.31	DRS
Côte d'Ivoire	100	100	100.00	CRS
Democratic Republic of the Congo	11.73	34.42	34.08	DRS
El Salvador	18.78	39.78	47.21	DRS
Equatorial Guinea	55.06	60.97	90.31	IRS
Eritrea	44.09	48.17	91.53	DRS
Georgia	15.82	30.92	51.16	DRS
Ghana	37.93	77.42	48.99	DRS
Guinea-Bissau	18.63	18.66	99.84	CRS
Honduras	19.67	42.67	46.10	DRS
India	100	100	100.00	CRS
Indonesia	56.73	66.55	85.24	IRS
Kenya	54.9	100	54.90	DRS
Kyrgyzstan	54.56	72.53	75.22	DRS
Lesotho	68.76	70.16	98.00	IRS
Madagascar	100	100	100.00	CRS
Malawi	100	100	100.00	CRS
Mali	100	100	100.00	CRS
Mexico	7.39	32.44	22.78	DRS
Mozambique	100	100	100.00	CRS
Myanmar	7.23	21.96	32.92	DRS
Niger	100	100	100.00	CRS
Nigeria	14.9	56.98	26.15	DRS
Paraguay	20.34	33.08	61.49	DRS
Peru	16.74	61.99	27.00	DRS
Republic of Moldova	15.44	26.92	57.36	DRS
Russian Federation	12.55	68.02	18.45	DRS
Rwanda	70.8	97.3	72.76	DRS
Sao Tome and Principe	100	100	100.00	CRS
Senegal	28.75	51.65	55.66	DRS
Tajikistan	8.43	19.6	43.01	DRS
Thailand	16.81	58.96	28.51	DRS
Togo	44.78	45.43	98.57	IRS
Ukraine	17.6	57.76	30.47	DRS
Viet Nam	4.96	22.14	22.40	DRS
Average	41.19596	58.79231	63.8093	
St Dev	34.37185	29.74814	30.46101	
Max	100	100	100	
Min	4.96	16.79	18.45046	

Note: IRS=increasing returns to scale; CRS=constant returns to scale; DRS=decreasing returns to scale.

Due to the exploratory nature of this research, some caution needs to be taken when we analyse these results. In spite of this, the results shown on Table 3 highlight some relevant aspects about the efficiency of each country in preventing mother-to-child HIV transmissions.

As can be seen from Table 3, we have broken down the technical efficiency score into pure technical efficiency and scale efficiency. In 2008, the average total efficiency score of the 52 countries was only 41%, with a standard deviation of approximately 34%, which indicates that there are considerable differences between countries and remarkable potential for improvement in some of them. In our study, only ten countries are classified as efficient under the assumption of a CRS technology: Botswana, Cameroon, Côte d'Ivoire, India, Madagascar, Malawi, Mali, Mozambique, Niger and Sao Tome and Principe. When we allow VRS, which seems to be a more appropriate assumption to adopt in this context, as explained previously, the average pure technical efficiency score is 58.8% and the number of efficient countries increases to twelve. This means that we have only two countries (Brazil and Kenya) that are technically efficient while operating under sub-optimal scale sizes. Both countries operate under decreasing returns to scale (DRS), which suggests that a smaller scale of operation (i.e. a lower domestic spending on the prevention of vertical transmission of HIV) would lead to a greater ratio of outputs over inputs. In fact, with regard to most of the countries that are technically inefficient, the DEA results suggest that they could benefit from decreasing their size of operation. These results seem to counter the findings of Marseille et al. [37], who found evidence that efficiency increased with scale. The only countries under analysis which could benefit significantly from operating at a higher scale are Equatorial Guinea and Indonesia (please refer to Table 3). Whilst scale seems to play an important role on the efficiency of some countries (e.g. Brazil, Kenya, Rwanda), others (e.g. Chad, Congo, Guinea-Bissau, Togo) could benefit mostly from a better use of the resources allocated to preventing mother-to-child HIV transmission, basically maintaining their size of operation.

In analysing the efficiency results it is also important to identify the optimal weight structure chosen by each country. Despite the fact that the DEA model may yield alternative optimal solutions for the weights, the different optimal weights identified can provide useful information. For instance, the different optimal output weight profiles are useful to identify different service delivery strategies. Table 4 illustrates some of these different strategies.

Table 4: Virtual weights attributed to the outputs by some countries under the VRS assumption (%)

	Output 1	**Output 2**	**Output 3**	**Output 4**
Botswana	8,2	8,2	54,4	29,2
Cameroon	25	25	25	25
Côte d'Ivoire	0	100	0	0
Equatorial Guinea	0	100	0	0
Guinea-Bissau	44,5	55,5	0	0
India	100	0	0	0
Indonesia	0	0	100	0
Kenya	36,6	5,4	52,6	5,4
Madagascar	100	0	0	0
Malawi	25	25	25	25
Mozambique	0	0	100	0
Nigeria	33,5	0	49,7	16,8
Sao Tome and Principe	25	25	25	25
Togo	0	0	100	0

As shown in Table 4, several different output weight profiles can be identified. Whilst some countries placed all the output weight in one of the outputs (e.g. Côte d'Ivoire, Indonesia, Madagascar), other countries distributed the weights between several or all outputs (e.g. Botswana, Cameroon, Kenya). The analysis of the results for the 52 countries shows that a large number of countries (22) have placed all the output weight on the output variable: “Reported number of pregnant women tested for HIV”. India and Madagascar are two examples of these countries: they have been classified as efficient, and placed 100% of the output weight on this output. A minority of countries also present an unbalanced profile of output weights, by placing all their weight on one of the other three outputs. For example, whilst Côte d’Ivoire and Equatorial Guinea have put all their output weights on the variable “Number of pregnant women living with HIV who received antiretrovirals for preventing mother-to-child transmission”, Indonesia, Mozambique and Togo have placed all their output weight on variable “Reported number of infants born to women living with HIV receiving antiretrovirals for preventing mother-to-child transmission”. Contrasting with this, we find three countries classified as efficient (Cameroon, Malawi and Sao Tome and Principe) that present a totally balanced weight profile, giving 25% of the weight to each output. The remaining countries present weights distributed unequally between two, three or all outputs.

Another interesting piece of information provided by DEA relates to the identification of benchmarks for each of the inefficient countries. Benchmarks are units that are classified as efficient when applying the optimal weight structure of the inefficient units under analysis. For example, as illustrated on Table 5, the benchmarks identified for Angola are Brazil, Malawi and Mozambique. These are the countries that Angola should use as a reference for learning.

Table 5: Peers and lambdas for some countries under the VRS assumption

	Brazil	Cameroon	Côte d'Ivoire	Malawi	Mozambique	Niger	Sao Tome and Principe
Angola	0.07			0.707	0.286		
Azerbeijan	0.023	0.003	0.974				
Burundi		0.276		0.101	0.033		0.59
Chad		0.158	0.275				0.567
Colombia	0.316		0.684				
Congo			0,401			0.29	0.309
Eritrea		0.043	0.087			0.533	0.337
Mexico	0.979	0.021					
Peru	0.212		0.788				
Thailand	0.5	0.326		0.174			
Number of times country *i* is used as a peer	**21**	**23**	**24**	**9**	**4**	**13**	**10**

Whilst some countries serve as benchmarks for a large number of countries (e.g. Brazil, Cameroon, Côte d’Ivore, Niger), others are classified as efficient but do not serve as a reference for other countries. From the 52 countries compared, Mali is the only one that has been classified as efficient but does not serve as reference to any other country. Mali has chosen a very peculiar weight structure: it places almost all its output weight on the third output (i.e. reported number of infants born to women living with HIV receiving co-trimoxazole prophylaxis within two months of birth). No other country benefits from this weight structure, which means that Mali has been classified as efficient because there is no other country to which it can be compared. In contrast, there are three countries that serve as benchmarks to more than 20 countries, presenting very robust efficiency status. These countries are: Côte d'Ivore, Cameroon and Brazil. These results indicate that the policies and service delivery strategies used by these three countries should be identified in order to provide guidance for other countries. This is the subject of future research.

In addition to the information regarding the benchmarks from which the inefficient countries can learn, Table 5 also provides useful information to define the targets to be achieved by these countries. This information is contained in the lambda values displayed in each of the rows of Table 5. For example, the values of the lambdas associated with Mexico (i.e. 0.979 and 0.021) represent the proportion of the service levels of Brazil and Cameroon that Mexico is required to provide to become efficient.

4 – Conclusion

In spite of the remarkable progress that has been made in recent years in battling the HIV/AIDS epidemic, this disease still poses huge challenges for individuals, households and nations. It is estimated that more than 1,000 children are newly infected with HIV every day, and of these more than half will die as a result of AIDS because of a lack of access to HIV treatment [1]. Over 90 percent of the children living with HIV were infected through vertical transmission from mother to the baby during pregnancy, delivery or breastfeeding. Considering that there is compelling evidence that appropriate prevention and care can reduce the rate of these transmissions significantly, it is imperative that nations ensure that this prevention and care reaches all pregnant women and children in need and that the resources are used as efficiently as possible.

In the academic literature there have been important contributions exploring the efficiency and cost-effectiveness of different HIV prevention programmes, including mother-to-child transmission. Most of these contributions have, however, been narrowed to a small region, a single country or parts of it, and have tended to rely on the use of a set of individual indicators detailing different aspects of service delivery. In this paper, we have explored the potential of using DEA to complement the existing literature in the area. To this effect we have proposed a model with two inputs and four outputs to compare, using data for 2008, the efficiency of 52 low- and middle-income countries in preventing mother-to-child HIV transmission.

Despite the exploratory nature of the research, there are some important empirical findings from our study. In particular, we found wide variation in terms of the efficiency of service provision across nations, indicating that some countries have been considerably more efficient in allocating resources to preventing HIV transmission from mother-to-child than others. This variation ought to be investigated as our preliminary results suggest that if all countries were using their resources efficiently, the level of service provision could increase by around 70 percent. Considering that the analysis reported in this paper also allows the identification of suitable learning peers to each nation, as well as targets for performance improvement, we believe it can be an important catalyst for a deeper formative assessment aimed at identifying the causes of poor performance, exploring the practices of the best performers; and based on this assessment to develop sound strategies for HIV prevention improvement.

The formative implementation of DEA in this context, however, faces some challenges. One of the most relevant is, perhaps, data unavailability. There are many countries for which there is no data, and even when data exists it does not cover all the important variables, or does not cover more than a year. Data unavailability might prevent the specification of appropriate models or might prevent the inclusion of countries in the analysis which could eventually change the efficiency frontier. Furthermore, when no panel data exists, it is not possible to perform dynamic assessments targeted at analysing eventual changes in the performance of nations over time. Another important challenge relates to the need of including weight restrictions in the models. In developing DEA models to assess the efficiency of countries in implementing particular HIV prevention policies it is important to decide whether it is acceptable to allow full flexibility in the choice of input and output weights. Whilst several approaches to define weight restrictions exist, the specification of appropriate weight restrictions can be a very challenging task.

It is important to emphasise that despite the fact that the successful application of DEA can be a challenge, DEA has a strong potential to contribute for performance improvement in this context. In particular, DEA is well suited to complement efficiency analyses undertaken by means of other methodologies.

In conclusion, we believe that DEA is a strong analytical technique upon which to build and which can play an important role in the development of efficient HIV prevention interventions. This paper has discussed some of the insights that derive from the use of DEA in this particular context. However, one of the premises of the authors of this paper is that DEA has to be broadened in order to contribute to performance improvement in practice. One of the main aspects of this broadening relates to the need to move away from the 'black box' type of evaluation, by incorporating the DEA exercise into case studies and context-driven research projects in order to facilitate the development of appropriate models and the implementation of the results in practice. Unless the results of these models are taken into consideration by decision makers and incorporated into the policy making process, their purposes are not served. Further research is being carried out by the authors in order to meet these objectives.

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References

[1] UNAIDS (2010) Global Report: UNAIDS report on the Global Aids Epidemic 2010. Joint United Nations Programme on HIV/AIDS

[2] International HIV/AIDS Alliance (2010) The cost efficiency of HIV prevention for vulnerable and most-at-risk populations and the reality of funding. International HIV/AIDS Alliance

[3] Lasry A, Sansom SL, Hicks KA, Uzunangelov V (2011) A model for allocating CDC's HIV prevention resources in the United States. Health Care Manage Sci 14:115–124. doi: 10.1007/s10729-010-9147-2

[4] Earnshaw SR, Hicks K, Richter A, Honeycutt A (2007) A linear programming model for allocating HIV prevention funds with state agencies: a pilot study. Health Care Manage Sci 10:239–252. doi: 10.1007/s10729-007-9017-8

[5] Brandeau ML, Zaric GS, De Angelis V (2005) Improved Allocation of HIV Prevention Resources: Using Information About Prevention Program Production Functions. Health Care Manage Sci 8:19–28

[6] Rauner MS, Brandeau ML (2001) AIDS policy modeling for the 21st century: An overview of key issues. Health Care Manage Sci 4:165-180

[7] Beck EJ, Miner AH (2001) Effectiveness and efficiency in the delivery of HIV services: economic and related considerations. In: Gazzard BG, Johnson M, Miles A (eds) The effective management of HIV/AIDS: UK key advances in clinical practice. Aesculapius Medical Press, London, pp 113-138

[8] Harling G, Wood R, Beck EJ (2005) Efficiency of Interventions in HIV Infection, 1994–2004. Dis Manage Health Outcomes 13(6):371-394

[9] De Cock KM, Fowler MG, Mercier E, de Vincenzi I, Saba J, Hoff E, Alnwick DJ, Rogers M, Shaffer N (2000) Prevention of mother-to-child HIV transmission in resource-poor countries: translating research into policy and practice. J Am Med Assoc 283(9):1175-82

[10] Appleby J, Thomas A (2000) Measuring performance in the NHS: what really matters?. Brit Med J 320:1464-1467

[11] Flessa S (2000) Where efficiency saves lives: A linear programme for the optimal allocation of health care resources in developing countries. Health Care Manage Sci 3:249–267.

[12] Ozcan YA, Smith P (1998) Towards a science of the management of health care. Health Care Manage Sci 1:1–4

[13] Royston G (1998) Shifting the balance of health care into the 21st century. Eur J Oper Res105:267-276

[14] Ruiz MS, Gable AR, Kaplan EH, Stoto MA, Fineberg H, Trussell J (eds) (2001) No time to lose: getting more from HIV prevention. National Academy Press, Washington DC

[15] Kaplan EH, Merson MH (2002) Allocating HIV-Prevention Resources: Balancing Efficiency and Equity. Am J Public Health 92(12):1905-1907

[16] Marseille E, Dandona L, Saba J, McConnel C, Rollins B, Gaist P, Lundberg M, Over M, Bertozzi S, Kahn JG (2004) Assessing the Efficiency of HIV Prevention around the World: Methods of the PANCEA Project. Health Serv Res 39(6):1993-2012

[17] Charnes A, Cooper WW, Rhodes EL (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2:429-444

[18] Banker RD, Charnes A, Cooper WW (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci 30:1078–1092

[19] Cooper WW, Seiford L, Tone K (2000) Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Kluwer Academic Publishers, Massachusetts

[20] Cooper WW, Seiford L, Zhu J (2004) Handbook on data envelopment analysis. Kluwer Academic Publishers, Massachusetts

[21] Ozgen H, Ozcan YA (2004) Longitudinal Analysis of Efficiency in Multiple Output Dialysis Markets. Health Care Manage Sci 7:253-261

[22] O'Neill L, Dexter F (2004) Market Capture of Inpatient Perioperative Services Using DEA. Health Care Manage Sci 7:263–273

[23] Langabeer JR, Ozcan YA (2009) The economics of cancer care: longitudinal changes in provider efficiency. Health Care Manage Sci 12:192–200. doi:10.1007/s10729-008-9079-2

[24] Hollingsworth B, Dawson PJ, Maniadakis N (1999) Efficiency measurement of health care: a review of non-parametric methods and applications. Health Care Manage Sci 2:161–172

[25] Hollingsworth B (2003) Non-Parametric and Parametric Applications Measuring Efficiency in Health Care. Health Care Manage Sci 6:203-218

[26] Chilingerian JA, Sherman HD (2004) Health care applications: from hospitals to physicians, from productive efficiency to quality frontiers. In: Cooper WW, Seiford LM, Zhu J (eds) Handbook on Data Envelopment Analysis. Kluwer Academic Publishers, London, pp 481–537

[27] Hollingsworth B (2008) The measurement of efficiency and productivity of health care delivery. Health Econ 17:1107-1128

[28] Zanakis SH, Alvarez C, Li V (2007) Socio-economic determinants of HIV/AIDS pandemic and nations efficiencies. Eur J Oper Res 176:1811–1838

[29] Beck EJ (1991) HIV infection and intervention: the first decade. AIDS Care 3(3):295-302

[30] Piot P, Zewkie D, Türmen T (2002) HIV/AIDS prevention and treatment. Lancet 360:86

[31] UNAIDS (2005) Q&A II: Selected issues: prevention, care and funding - UNAIDS Questions & Answers. Joint United Nations Programme on HIV/AIDS.

[32] Bryson YJ (1996) Perinatal HIV-1 transmission: recent advances and therapeutic Interventions. AIDS 10(Supplement 3):S33–S42.

[33] Zachariah R, Harries AD, Luo C, Bachman G, Graham SM (2007) Scaling-up co-trimoxazole prophylaxis in HIV-exposed and HIV-infected children in high HIV-prevalence countries. Lancet Inf Dis 7(10):686-693

[34] Marseille E, Kahn JG, Mmiro F, Guay L, Musoke P, Fowler MG, Jackson JB (1999) Cost effectiveness of single-dose nevirapine regimen for mothers and babies to decrease vertical HIV-1 transmission in sub-Saharan Africa. Lancet 354(9181):803–809

[35] Quinn T (1996) Global burden of the HIV pandemic. Lancet 348:99–106

[36] Emrouznejad A, Thanassoulis E (2005) Performance improvement management. DEASoft, Pim Ltd.

[37] Marseille E, Dandona L, Marshall N, Gaist P, Bautista-Arredondo S, Rollins B, Bertozzi SM, Coovadia J, Saba J, Lioznov D, Du Plessis J, Krupitsky E, Stanley N, Over M, Peryshkina A, Kumar SG, Muyingo S, Pitter C, Lundberg M, Kahn JG (2007) HIV prevention costs and program scale: data from the PANCEA project in five low and middle-income countries. BMC Health Serv Res 7(1):108. doi:10.1186/1472-6963-7-108

[38] Brandeau ML, Zaric GS (2009) Optimal investment in HIV prevention programs: more is not always better. Health Care Manage Sci 12:27–37. doi: 10.1007/s10729-008-9074-7

[39] Sarrico CS, Dyson RG (2004) Restricting virtual weights in data envelopment analysis. Eur J Oper Res 159(1):17-34