UNIVERSIDADE DO ALGARVE

FACULDADE DE ECONOMIA

EFFECTIVENESS IN THE PREVENTION AND CONTROL OF TUBERCULOSIS – A COMPARATIVE ANALYSIS OF COUNTRIES USING DATA ENVELOPMENT ANALYSIS

ANA RITA SALVÉ-RAINHA GASPAR

Dissertação para obtenção do grau de Mestre em Gestão de Unidades de Saúde

Mestrado em Gestão de Unidades de Saúde

Trabalho efetuado sob orientação de:

Professora Doutora Carla Alexandra E. Filipe Amado

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Ana Rita Salvé-Rainha Gaspar

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LIST OF ABBREVIATIONS

AIDS – Acquired Immunodeficiency Syndrome

CI – Composite Indicator

CRS – Constant Return to Scale

DEA – Data Envelopment Analysis

DMU – Decision Making Unit

DOTS – Directly Observed Treatment Short-coursed

EMS – Efficiency Measurement System

HBC – High Burden Country

HIV – Human Immunodeficiency Virus

MDR – Multi-drug resistance

MDR-TB – Multi-drug resistant tuberculosis

NTP – National Tuberculosis Control Program

RR – Rifampicin Resistance

RR-/MDR- - Rifampicin Resistant-/Multi-drug Resistant

RR-/MDR-TB - Rifampicin Resistant-/Multi-drug Resistant Tuberculosis

TB - Tuberculosis

WHO – World Health Organization

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To all those who, during this journey, were somehow harmed by my absence. The choices were not always easy and only your strength and your smile gave me the courage to continue. My success is due to you.

RESUMO

A Tuberculose é a primeira causa de morte por doenças infeciosas em todo o mundo. O atual panorama de restrições que a maioria dos países atravessa, reforça a avaliação da eficiência e efetividade, como a única forma de orientação para que os investimentos feitos assentem sobre uma base sólida de boas práticas e melhoria contínua.

O presente estudo tem como objetivo explorar o uso da técnica *Data Envelopment Analysis* (DEA) por forma a analisar o desempenho dos países no que se refere ao controlo da Tuberculose e identificar boas práticas como uma plataforma de melhoria. Para esse efeito, utilizamos dados de 33 países de baixo e médio rendimento referentes ao sucesso de tratamento. Os resultados mostram que o Bangladesh, Burundi, China e Paquistão são os únicos países efetivos na nossa amostra. Apesar da variação da efetividade entre países não ser substancial, os resultados mostram margem para melhorias e sugerem que uma melhor utilização dos recursos e práticas mais efetivas de prevenção e controlo podem ser estabelecidas. Além disso, os nossos resultados também apoiam o DEA como uma ferramenta versátil para o planeamento estratégico e tomada de decisões efetivas.

Palavras-chave: Tuberculose, Prevenção e Controlo, Data Envelopment Analysis, Efetividade;

ABSTRACT

Tuberculosis (TB) is the first cause of death from infectious diseases worldwide. The current panorama of restrictions that most of the countries are experiencing, makes it necessary to assess efficiency and effectiveness as the only way to provide guidance so that the investments made can have a sound basis of good practice and continuous improvement.

The present study proposes to explore Data Envelopment Analysis (DEA) to assess countries performance in TB prevention and control, and in doing so establish comparisons between countries and identify good practices as a platform for improvement. To achieve these objectives, we used data regarding TB treatment success from 33 low and middle income countries. Our results show Bangladesh, Burundi, China and Pakistan as the only effective countries in our sample. Despite the variation of effectiveness not being substantial, our results show margin for great improvement and suggest that a better use of resources and more effective practices regarding TB prevention and control can be established for the non-effective countries. Moreover, our results also support DEA as a versatile tool for effective strategic planning and decision making.

Keywords: Tuberculosis, Prevention and Control, Data Envelopment Analysis, Effectiveness.

1. INTRODUCTION

Tuberculosis (TB) is today, according to the World Health Organization (WHO), the number one cause of death from infectious diseases worldwide, along with the Human Immunodeficiency Virus (HIV). Despite all the efforts made, and knowing that TB is preventable and curable, numbers show that this disease has a global massive representation and creates an urgent need for effective strategies to control it and prevent the appearance of new cases. The WHO (2016) points to an estimated 10,4 million new TB cases worldwide in 2015. This represents 800.000 more cases than those estimated in the report published in 2015. The high number of TB cases worldwide has major repercussions in countries' budgets and creates financial gaps that can make treatment inaccessible for those who need.

Treatment success (including completed treatment or cured patients) is remarkably important for TB control programs, as non-adherence can contribute to the ongoing spread of this disease and the emergence of multi-drug resistant TB (MDR-TB) in the community (Okanurak, Kitayaporn & Akarasewi, 2008). In this scenario, an early diagnosis of infected people and an adequate monitorization during the course of treatment are both milestones in stopping TB and the most effective strategy in preventing this disease from spreading.

TB control programs face several difficulties and challenges throughout their implementation. The lack of a structured and solid funding, a poor government commitment and deep difficulties in implementation and surveillance require simple but effective measures, as we need to have in mind that the most affected TB countries are greatly affected by poverty. In these countries, wasting money with ideal but not real policies is not an option. Indeed, it is imperative to assess if strategies and countries' policies are truly effective and efficient. We need to be conscious that health systems everywhere could make better use of their resources, whether through better practices, more widespread use of generic products, better incentives to providers, or more fluid financial and administrative mechanisms (Chan in World Health Report, 2010). The current panorama of restrictions that most of the countries are experiencing, makes it necessary to take a more critical and reflexive look at the health policies and programs of the various countries. The assessment of efficiency and effectiveness plays an increasingly significant role, as the only way to provide guidance so that the investments made can have a sound basis of good practice and continuous improvement.

Data Envelopment Analysis (DEA), developed by Charnes, Cooper and Rhodes (1978), is a non-parametric linear programming technique intended to measure the relative efficiency of Decision Making Units (DMU). More than that, it allows the identification of best performers and the establishment of comparisons among countries through a benchmark group. The information obtained by the identification of best practices can guide decision makers in the definition of better policies to improve the performance of countries (Zanella, Camanho & Dias, 2013).

Therefore, the aim of this study is to assess countries effectiveness in the prevention and control of TB by using the DEA technique. In doing so, we can establish comparisons between countries and identify the most effective practices so that others can learn through them. As far as we know, there are no published papers crossing DEA and countries performance regarding TB prevention and control. As a consequence, we believe that the present study will add valuable knowledge to this area. Furthermore, it is also our aim that managers, policy makers and decision takers use this knowledge as a platform for improvement.

2. EFFECTIVENESS IN THE PREVENTION AND CONTROL OF TUBERCULOSIS

2.1 PREVENTION AND CONTROL OF TUBERCULOSIS

TB was declared a global public health problem in 1993 by the WHO and with this declaration, several strategies were developed to fight this disease. According to the WHO, TB was the 2nd cause of death from infectious disease worldwide in the year of 2014. More recent data from the same organization, shows that the numbers have grown. In fact, TB became the 1st cause of death from infectious diseases worldwide in 2015, alongside HIV (WHO, 2015; WHO, 2016).

Despite what seems to be a negative scenario with growing numbers playing a major role, it is important to notice that this increase can be due to increased reporting. Several countries, such as China, India, Egypt and Peru made substantial progress in their public health communicable diseases reporting systems. Particularly in China, public hospitals are responsible for 55% of all reported cases and a web-based system for the reporting of communicable diseases has been implemented.

Globally speaking, it is estimated that in 2015 alone, 10,4 million new cases of TB have emerged (WHO, 2016). This represents 6 million more new cases than in 2013 and 800.000 more cases than first estimated by the WHO's report from 2015. In financial terms, the expression of these numbers assumes enormous proportions in all countries budget. Indeed, the average cost per person in 2015, oscillated between 100-1000 US dollars for drug-sensitive TB and 2000-20000 US dollars for MDR-TB (WHO, 2016). The overall value of prevention, diagnosis and treatment in 2014 and 2015 was estimated to be over 6.6 billion US dollars (WHO, 2014; WHO, 2015).

Since 1990 until 2015, TB mortality has fallen 47%. In all, effective diagnosis and treatment saved an estimated 43 million lives between 2000 and 2014 (WHO, 2015). The advances were indeed major, but effective management strategies are still needed. Despite all the efforts made, TB still holds an extremely significant role in the world of diseases, as it is estimated that 1.4 million persons died from TB in 2015 and for each three persons who develop TB, one is still either not diagnosed or not reported. In fact, TB remains a major public health problem. The lack of timely access to quality diagnostic and treatment services for vulnerable populations contributed to the spread of TB and drug resistance (Khan, Fletcher & Coker, 2016).

In what refers to success rates, globally, the treatment success rate for people newly diagnosed with TB was 86% in 2013 (WHO, 2015; WHO, 2016). A level that has been maintained since 2005. Although the target of 85% treatment success imposed by the WHO was achieved, the numbers show discrepant scenarios among the six WHO regions. The highest treatment success rates in 2013, were observed in the Western Pacific Region, the South-East Asia Region and the Eastern Mediterranean Region with, 92%, 88% and 91%, respectively. Whilst in the African Region the treatment success rate was 79%, the lowest numbers were observed in the Region of the Americas and the European Region, with 75% and 76%, respectively. This shows a severe increase in treatment success since 1995, however, the differences between regions provides evidence that best practices need to be identified. A learning process based on the experiences of the best practices regarding TB prevention and control is fundamental to improve the performance of the different regions and to achieve the WHO's targets.

Among all the countries that report information about TB to the WHO, there are 22 that hold the highest incidence rate of TB. The WHO considers Angola, Bangladesh, Brazil, China, Democratic People's Republic of Korea, Democratic Republic of Congo, Ethiopia, India, Indonesia, Kenya, Mozambique, Myanmar, Nigeria, Pakistan, Philippines, Russian Federation, South Africa, Thailand, Tanzania, United Republic of Viet Nam, Cambodia, Central African Republic, Congo, Lesotho, Liberia, Namibia, Papua New Guinea, Sierra Leone, Zambia and Zimbabwe, to be the 22 high burden countries (HBC), as, together, they are responsible for 83% of all cases reported. According to data published in the Global Tuberculosis Report of 2015 (WHO, 2015), most of these countries have rates of new cases around 150 to 300 per 100.000 inhabitants. Moreover, the mortality rate in these countries oscillated between 790.000 and 1.100.000 deaths excluding deaths among HIV-positive patients. Between HIV-positive patients the mortality rate fell between 280.000 and 360.000 deaths. The high numbers of cases, as well as the high mortality rates, which represent between 81% to 85% of the global mortality rate, make clear the concrete and fundamental need for effective actions to fight this disease, not only for the obvious expenses associated with it but, and above all, to avoid the loss of health and quality of life that it causes.

The prevention, diagnosis and treatment of TB is a challenge for all those who care about health and well-being and brings out the need for an efficient intervention guided by scientific knowledge and good management practices. It is remarkably important to understand if concerted efforts are truly effective and efficient. Indeed, when we talk about effectiveness (the extent to which the system achieves the objectives set) and efficiency (the extent to which the system uses the resources to maximize the delivery of services) we need to realize that there is potential to improve. For example, it has been argued that health systems could make better use of their resources, by implementing best practices, making a more widespread use of generic products, providing better incentives or applying more fluid financial and administrative mechanisms (Chan in the World Health Report, 2010). Effective action involves a systemic and agile look and requires proper management of resources.

Due to this fact, the achievement of efficiency and effectiveness became a major priority for managers, directors and other stakeholders. There must be a clear understanding of the difficulty, but also the fundamental need, to systematically conjugate these two concepts. The search for efficiency and effectiveness should aim to guarantee not only the aspects of the best use of resources and the best possible results, but should also be seen as the only way to provide the best possible care to TB patients.

TB control programs face several difficulties and challenges throughout their implementation. The lack of a structured and solid funding, a poor government commitment and deep difficulties in implementation and surveillance are examples of these challenges (Jassal & Bishai, 2010). To address them, simple but effective actions are required. We need to have in mind that the most affected TB countries are greatly affected by poverty and therefore cannot waste money with ineffective and inefficient actions.

Choosing the appropriate indicators is pointed out as a critical issue in monitoring and evaluating TB control programs (Cherchye, Moesen, Rogge & Van Puyenbroeck, 2007; Cherchye, Moesen, Rogge, Van Puyenbroeck, Saisana, Saltelli, Liska and Tarantola, 2008). Indeed, some of the most important organizations in shaping healthcare policy have worked on this issue and developed methods to monitor and evaluate National TB Programs. In spite of this, to the best of our knowledge, there is no method available to compare, in aggregated terms, the performance of countries with respect to TB programs. However, as discussed by Cherchye *et al.* (2008), the WHO, the United Nations and other international organizations have developed composite indicators (CIs) to compare countries in other complex policy issues. These CIs aggregate the performance of several indicators into a single number.

Indicators like coverage, case detection, and treatment success embody the three key global indicators recommended by the World Health Assembly for measuring national TB control program. The Compendium of Indicators for Monitoring and Evaluating National Tuberculosis Programs (WHO, 2004), clarifies, among concepts and other indicators, the use of these three indicators and explains how they should be interpreted. Due to the importance of treatment success in preventing TB from spreading and drug resistance from developing, we felt the need to specifically refer to this concept. Indeed, the treatment success rate is defined as

> *"the percentage of a cohort of TB cases registered in a specified period that successfully completed treatment, whether with bacteriologic evidence of success ("cured") or without ("treatment completed")"*
>
> (WHO, 2004: 37)

Treatment success represents a clear benefit for the person itself, but more than that, it is an enormous step to stop TB from spreading. Therefore, treatment success is directly related to reduced TB mortality. As an indicator, TB treatment success measures the capability of a program to hold the patients through the, sometimes very long, course of treatment.

When, in 1991, the WHO set a target of 85% for this indicator, only those cases which had bacteriologic evidence of success after treatment (cure) were considered. Later, the WHO started including also the persons who have completed treatment even without evidence of being cured. This target has been accomplished in the case of drug-susceptible TB since 2007. However, when we refer to drug-resistant TB, the treatment success was only 48% in the year of 2012. This is a number far from the established targets and that shows the substantial improvements that need to be done.

Assessing and monitoring TB in terms of treatment success, the objective of this dissertation, allows us to understand if countries strategies are producing effects and making progress is the fight against TB. In doing so, we can realize what countries are effective, identify their practices and learn from them, so that progress can be a constant process in countries' agenda. Only an effective performance assessment can guarantee an adequate use of funds, improvements in quality of life and a safer world to live in.

2.2 THE USE OF DATA ENVELOPMENT ANALYSIS TO ASSESS EFFECTIVENESESS

To assess effectiveness there are many techniques that can be used. The most frequently used approaches for performance assessment are: ratio analysis, the parametric approach, and the non-parametric approach, known as Data Envelopment Analysis (DEA). Whilst the ratio analysis involves the comparison of several performance indicators in the form of ratios, the parametric approach involves the assessment of performance based on a comparison with a best practice frontier with a shape as hypothesized by the analyst. Concerning DEA, it involves the assessment of performance regarding a non-parametric performance frontier. As opposed to the parametric approach, DEA identifies the best practice frontier based on the observed data, without the need for assumptions about its shape. For this reason, as discussed by Hollingsworth (2003), DEA has become the dominant approach for performance assessment in healthcare as well as other sectors.

Although initially intended to assess productive efficiency of "not-for-profit entities" (Charnes, Cooper & Rhodes, 1978: 1) participating in public programs, nowadays its use seem to have expanded to other realities. Cherchye *et al.* (2007) note that the scope of DEA has broadened substantially over the last two decades, including macro-assessments of countries, productivity and performance assessments and several applications to composite indicators construction.

Going back to the foundations of DEA, in what refers to productive efficiency, Farrell (1957) by continuing Koopmans (1951) and Debreu (1951) work, defined this concept as the product of technical and allocative efficiency. Being more specific, Kopp (1981) defines productive efficiency as the ability of production organizations to produce a well-specified output at minimum cost, where the output and factor inputs must be clearly specified by vectors of measurable features.

Giving attention to Farrell's definition, it becomes easy to understand that the concept of technical and allocative efficiency are indeed easily distinguished but at the same time connected to each other. The first one is associated with the production frontier, which considers that an organization is efficient when produces the maximum output from a specified set of inputs, while the second one measures an organization's success in selecting an ideal set of inputs with a certain set of input prices (Cooper, Seiford & Zhu, 2011). Regarding allocative efficiency, Kopp (1981) clarifies that it involves the selection of the most adequate input mix that allocates factors to their highest valued uses and thus introduces the opportunity cost of factor inputs in the measurement of productive efficiency.

Even though DEA has been mostly used to measure the relative efficiency of units, there are also a few authors using DEA to measure effectiveness. Golany (1988), Schinnar, Kamis-Gould, Delucia & Rothbard (1990), Asmild, Paradi, Reese & Tam (2007) and Amado & Dyson (2008) are examples of some authors that have used DEA with the aim of evaluating effectiveness. According to Asmild *et al*. (2007), in the absence of precise prices or other value measures, models incorporating weight constraints such as DEA models can be used to determine effectiveness. Indeed, when Golany (1988), affirms that effectiveness measures how close an entity performs relative to some given goals and argues that inefficiency is associated with waste, and, therefore, cannot be associated with effective operations, we can see the proximity between these two concepts.

Generally speaking, effectiveness assesses the beneficial impact of strategies in real healthcare outcomes (the impact on the relevant stakeholders). It evaluates the extent to which the aims of a particular organization are achieved. When healthcare and economics study fields cross over, effectiveness is in fact what makes more sense to measure and to have in consideration when strategies are planned. To talk about effective strategies is to talk about positive impact and about real changes in people's quality of life.

DEA was initially proposed by Charnes, Cooper & Rhodes (1978), and consists in a non-parametric linear programming model that allows to evaluate the performance of a set of DMUs and that considers that each DMU integrates a process of transforming a set of inputs (resources) into outputs (goods/ services) (Cooper, Seiford & Zhu, 2011*)*. Overall, DEA measures efficiency by estimating an empirical production function which embodies the optimal amount of outputs that could be generated by the inputs (Golany, 1988; Lovell, Pastor & Turner, 1995). This said, a DMU's efficiency/inefficiency is measured by the distance from the point which represents its input and output values to the production frontier. Furthermore, DEA gives the possibility of benchmarking in operations management and just requires general information of production and distribution (Cooper, Seiford & Zhu, 2011).

More than simply compiling results of efficiency for each DMU, DEA also allows each unit to identify a benchmarking group. These groups are made by units that, despite sharing goals and priorities with other units, appear to have a better performance and so are considered to be more efficient (Santos, Amado & Santos, 2012; Dear & Dyson, 2008). In this respect, by comparing the inefficient units with the efficient ones, it is possible to find ways to reduce inefficiencies.

In this regard, Cherchye *et al*. (2007) developed their work around CIs and weight restrictions. In what refers to CIs, they represent indices that compile several individual performance indicators. This aggregation is undertaken by applying a specific weight to each performance indicator and measures multi-dimensional concepts that cannot be captured by a single indicator. These authors explain the "benefit-of-the-doubt" approach to construct CIs, in which "the weighting problem is handled for each country separately, and the country-specific weights accorded to each sub-indicator are endogenously determined" (Cherchye *et al*., 2007: 119). In this perspective, the main idea is that a country's good relative performance in one specific sub-indicator points to a higher policy significance. Since one does not have information about the true weight policy of a country, one can collect that information by identifying the country's relative weaknesses and strengths (Cherchye *et al*., 2007; Cherchye *et al*., 2008).

Therefore, these authors named above, affirm that such a data-oriented weighting model is justified by the typical CI-context of uncertainty, and lack of consensus on an appropriate weighting scheme.

The use of DEA to develop CIs has been very popular and numerous papers can be found illustrating its use. Cherchye, Moesen & Puyenbroeck (2004), Zanella *et al.* (2013) are just a few examples of studies that have used DEA with the "benefit-of-the-doubt approach" to compare the performance of countries in several different contexts. In the case of Zanella *et al.* (2013), these authors used a CI based in 25 single indicators that underlie the estimation of the Environmental Performance Index, to assess countries' environmental performance. To ensure that all countries were being evaluated homogeneously they imposed weight restrictions and identified which countries are examples of best practices and which need to improve their results. By comparing the obtained ranking of countries with the ranking of the Environmental Performance Index, they tested the robustness of the results and verified that a positive relation exists between the approaches.

In the healthcare field, Santos *et al.* (2012), conducted a study to assess the efficiency in preventing mother-to-child HIV transmission. With a sample of 52 low and middle income countries, these authors also chose to impose weight restrictions and by that, to prevent the countries from attributing a null weight to the variables. Through their DEA model, they concluded that there are significant variations between countries in matter of services provided. Some of the countries could make a more efficient use of the resources and, in doing so, could increase their performance around 70%. Moreover, they identified the non-efficient countries, the countries with best practices and set targets for improvement. In fact, they showed the potential of the DEA features and their importance for strategic planning in healthcare.

In any of the studies reported above, one of the main challenges faced by the authors was to identify the appropriate performance indicators to include in the analysis. By indicator we mean a section of information that provides evidence about a specific phenomenon. However, a single indicator is not enough to make assessments and take conclusions given that it is just a small piece of a multi-dimensional phenomenon. Thus, the composite indicators, as a combination of a set of sub-indicators, were developed to give a broader idea regarding the performance of an entity. They summarize complex and multi-dimensional issues in a mathematical combination of individual indicators that represent different dimensions of a concept, which cannot be captured by a single indicator (Saisana & Tarantola, 2002; Zanella *et al.*, 2013).

The CI's construction formula adapted from Cherchye *et al*. (2007) is as follows:

$$CI_j = \sum_{i=1}^{m} w_{ij} \cdot y_{ij}$$

In this, CI_j ($j=1,\ldots, n$) is the composite index for country j, n represents the number of DMU's, m is the number of performance indicators, y_{ij} is the value of indicator i generated by country j (i = 1,... m) and w_i the weight assigned to indicator i. The resulting composite index can vary between zero, that represents the worst possible performance, and 1 (the benchmark).

The fact that DEA does not impose a rigid structure of input and output weights for each unit is also pointed as an advantage of this technique. Thus, the weights are identified by the optimization problem and assume values that allows each DMU to achieve the best possible efficiency result. This flexibility assumes important proportions when we intend to identify the inefficient DMU's, as it validates that they are not capable of accomplishing efficient results even when we use a weight distribution that favors them. Therefore, because of this absolute freedom, in a conventional DEA model, there are some inputs and/or outputs that can assume a weight close to zero and, as a consequence, be almost ignored in the efficiency analysis, despite any previous information about the DMU's purpose and alleged importance of that input/output. Lins, Silva & Lovell (2007), point this situation as one of the most severe limitations of the conventional DEA models.

From this fact, rises the need to restrain the excess of freedom and impose limits to reach a balance between flexibility and data information. Indeed, several researchers, such as Wong & Beasley (1990), Roll, Cook & Golany (1991) and Dimitrov & Sutton (2010) tried to find this balance and created models with weight restrictions. Pedraja-Chaparro, Salinas-Jimenez & Smith (1997) and Chercye *et al.* (2007), have also recognized the usefulness of these models and explained them in their work.

However, imposing weight restrictions is not an easy task. Restricting weights can be a difficult task due to possible conflicting expert opinions on the proper restrictions and due to problems with infeasibility (Dimitrov & Sutton, 2010).

In terms of the formulation of weight restrictions, there are a number of approaches suggested in the literature, most of which operate on the basis of judgements of importance about the inputs and outputs, based on monetary values, or based on production trade-offs. In this paper, we are just going to explain weight restrictions based on the "trade-off approach", proposed by Podinovski (2004), since this is the method we use in this dissertation. We have chosen to use this approach since, as discussed by Podinovski (2004), it has several advantages: it avoids infeasibility and it ensures that the performance targets are realistic. According to the same author, this method guarantees that the radial target of inefficient units is always producible, since the restrictions are formulated based on realistic technological trade-offs. This situation cannot be guaranteed when we define weight restrictions based on the other two approaches mentioned above (judgements of importance and monetary values). In these cases, the resulting efficiency assessment can no longer be interpreted as a realistic improvement factor (Podinovski, 2004; Podinovski, 2016).

As the "trade-off approach" gives us the possibility of imposing restrictions and at the same time ensures that realistic targets are estimated, it seems the best choice for our model.

In some contexts, we are interested in comparing countries with respect to their achievements, without being concerned about the level of resources that was used to produce the results. That means that we are interested in evaluating the relative effectiveness of the countries without a concern for the level of relative efficiency. In these cases, the DEA model needs to be modified to include a single unitary input and several outputs. According to Lovell *et al*., (1995: 509), "this assumption implies that one input, the helmsman, provides varying amounts of several services, and that every country-year observation has exactly one helmsman". This single input is also called "dummy input" (Cherchye *et al*., 2007: 121). In this perspective, the results we obtain are focused only on the achievements without evaluating the inputs required to achieve them.

Indeed, Amado, José & Santos (2016) developed their study around a benefit-of-the-doubt DEA model related to the measurement of active ageing in the European Union, with output orientation and using a single unitary input. These authors present the mathematical formulation for the benefit-of-the-doubt model as follows:

$h_L = Min\ v$

Subject to:

$$\sum_{r=1}^{s} u_r y_{rL} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - v \leq 0$$

$$v \geq \varepsilon > 0$$

$$u_r \geq \varepsilon > 0$$

In this sense, s represents the number of outputs, u_r is the output weight or the multiplier associated with output r, y_r represent the outputs ($r=1, \ldots, r$), hL is the relative score of the country, j represents each of the n countries ($j, \ldots, n$) and v is the weight of the single input. For the present study, we add to this formulation 12 weight restrictions in the form of trade-offs, which will be presented in the next chapter.

Based on this model, countries can take conclusions regarding their own results, compare their performances with the benchmarks and adjust their policies according to the best practices. Due to its characteristics, the model can be used to assess the effectiveness of countries. We would like to recall that assessing effectiveness assumes extreme importance in healthcare, not only for managers, directors and administrators, but also, and above all, for patients, as the only way to pursue excellence.

Despite the extensive use of DEA in the healthcare context, to the best of our knowledge, there are no published papers that compare countries in terms of the effectiveness of TB prevention and control. Due to this fact, the present paper undertakes the important task of exploring this issue with the aim to identify the most effective countries in this context, as well as understand the structures and processes that support their best practices.

3. DATA ANALYSIS

3.1 DEA MODEL

In order to choose the appropriate set of inputs and outputs for our DEA model, several documents were consulted. Unfortunately, as far as we are aware, there are no published studies we can refer to in what regards the use of DEA to assess countries effectiveness in TB prevention and control. Consequently, we constructed our model with the information provided by WHO's annual reports, which include data about several indicators and allow us to choose the variables that are most suitable for the purpose of our study.

Since the present dissertation focuses on an evaluation of effectiveness, in which the fundamental purpose is to maximize results/outcomes, the choice of inputs turned out to be very clear. Following the approach suggested by other authors (such as, for example, Cherchye *et al.*, 2007*)*, we used a single input equal to one, or in other words a "dummy" input. Its use only makes sense when we want a model that is only concerned with achievements.

Based on our review of the WHO reports, we have selected the following four outputs to include in the DEA model:

1. Treatment success rate for new and relapsed TB cases;
2. Treatment success rate for previously treated TB cases, excluding relapses;
3. Treatment success rate for HIV-positive TB cases;
4. Treatment success rate for Rifampicin Resistant-/Multi-drug resistant- (RR-/MDR-) TB cases.

Treatment success, alongside with directly observed treatment, short-coursed (DOTS) coverage and case detection rate, is a key global indicator recommended by the World Health Assembly for measuring national TB program's success.

Adherence to TB treatment is especially important for TB control. Non-adherence can contribute to the ongoing spread of the disease and the emergence of drug-resistant TB in the community (Okanurak *et al.*, 2008). Considering that TB treatment requires taking several drugs for at least 6–8 months and that numerous adverse effects can happen, patients do not always finish it. It should also be mentioned that, because after a few weeks of taking the drugs the patients start feeling better, the need for continuing treatment is sometimes not perceived by them and so they tend to abandon it. Therefore, treatment success rates are dependent on this adherence and evaluate the capability of countries TB programs to retain the patients until the course of treatment is finished. Its importance is major in stopping TB globally.

The calculation of this indicator is made by the following formula:

$$\frac{\begin{gathered}Number\ of\ new\ smear\ positive\ pulmonary\ TB\ cases\ registered\ in\ a\\ specified\ period\ that\ were\ cured + \ the\ number\ that\ completed\ treatment\end{gathered}}{\begin{gathered}Total\ numer\ of\ smear\ positive\ pulmonary\ TB\ cases\ registered\\ the\ same\ period\end{gathered}}\ X\ 100$$

Treatment success rate is an outcome indicator, so it reflects the changes, or in other words the broader results, that are expected to occur with the use of the inputs. The numbers needed to calculate this indicator are reported quarterly to the WHO at a facility, district, regional and national level. For this study, we consider only the national level data as, according to the WHO (2004), it allows comparisons between countries.

Specifically referring to our first output, it is important to clarify the term "relapsed cases" and to make a distinction between this and "previously treated cases" of TB. Some confusion may occur when we look at these two concepts. The WHO (2011) defines that the relapses occur in patients that had TB and after treatment stayed without it for a period. They consider these patients as having a new TB episode and not the same one. In contrast, previously treated cases (after failure or after default) are cases in which the prolongation of a TB episode requires a change in the treatment. Indeed, the new and relapsed cases are treated as one category of patients in what refers to reporting information to the WHO (our first output), and previously treated patients are handled in separate (our second output).

About this second output, it is also important to emphasize that the cases that have been previously treated, have a higher probability of having a RR-/MDR-TB, and therefore should be tested for drug resistance. These patients require a treatment regimen that differs from patients that were not previously treated.

In addition to classifying cases by their treatment history, the numbers published by the WHO are also differenced by HIV status and multi-drug resistance (MDR) status. Since the risk of having TB is estimated to be 26 to 31 times higher in people living with HIV than among those without HIV infection, this category of patients demands special attention and requires specific collaboration strategies between WHO's HIV and

TB departments. Consequently, our third output refers to "treatment success rate for HIV-positive TB cases".

Lastly, referring to the fourth output, it is important to clarify the RR-/MDR-TB definition. The WHO (2011) defines it as the infection caused by Mycobacterium tuberculosis resistant in vitro to the effects of rifampicin (RR) or isoniazid and rifampicin (MDR), with or without resistance to any other drugs. Therefore, this diagnosis is made based on drug sensibility tests, which may be crucial in defining the course of treatment for these patients. It is estimated that in 2015 there were 480.000 cases of MDR-TB and 110.000 of RR-TB (WHO, 2016). Although the number of patients with this type of TB are significantly lower than the number of patients with drug-sensitive TB, treatment success is more difficult to achieve because treatment courses require adjustments to the drug resistances and last for at least 2 years. In WHO's reports, the information about these patients are reported in separate and, because of that, this category is also handled in separate in our DEA model.

It is important to emphasize that the right selection of outputs for the DEA model is fundamental for the robustness of the results we present below. These four outputs were selected because of their importance, recognized by the WHO, and having in attention the availability of the information. In fact, the choice of these outputs is justified by the need to treat the different categories of patients separately, but also by the fact that the reporting systems do not capture information regarding other TB high risk groups. The only at-risk groups for which information is available are HIV patients and RR-/MDR-TB patients, and so these were the separate groups that could be included.

In summary, table 1 presents the input and outputs considered in our DEA model:

Table 1: Summary of the input and outputs included in the DEA model

Inputs	*Outputs*
Dummy input	Treatment success rate for new and relapsed TB cases;
	Treatment success rate for previously treated TB cases, excluding relapses;
	Treatment success rate for HIV-positive TB cases;
	Treatment success rate for RR-/MDR- TB cases.

In terms of describing our DEA model, it is also relevant to clarify the restrictions imposed and why we choose to impose them. Considering that the countries under analysis (i.e. high burden TB countries) have the same generic goals regarding TB prevention and control, it was considered unacceptable and unrealistic to allow the DEA model to assign to their outputs very discrepant weights. Thus, we felt the need to limit the level of flexibility in the choice of weights, in order to avoid the possibility of some countries assigning a weight close to zero to some of the outputs.

We consider that the analysis of the proportion of patients accounted by each output in the total of TB patients for a particular country, is a realistic piece of information that can be taken into account in the definition of the weight restrictions. To formulate these restrictions, we gave special attention to the maximum and minimum values of this ratio. Considering that they can translate the *trade-offs* expected to occur between outputs, based on this information, we can establish restrictions that reflect realistic information about the countries. Consider the following codification of variables:

- *"v1"*: number of new and relapsed cases;
- *"v2"*: number of previously treated cases, excluding relapses;
- *"v3"*: number of HIV-positive TB cases;
- *"v4"*: number of RR-/MDR-TB cases.

Table 2 below shows the results we obtain when we divide the number of cases included in each of the 4 categories of outputs by the cases included in the others.

Table 2: Summary of the ratios between the TB cases included in each category

	v1/v2	*v1/v3*	*v1/v4*	*v2/v3*	*v2/v4*	*v3/v4*
Maximum	294,33	8979,64	1774,38	192,65	73,06	445,37
Minimum	4,19	1,26	1,95	0,03	0,06	0,04

With these ratios, one can tell, for example, that in a given country for each successfully treated case of TB in previously treated patients, we have approximately 294 new or relapsed cases also treated with success. This is the maximum ratio observed. The minimum ratio observed is of 4,19. We have defined weight restrictions that limit the ratio of weights between variables to be consistent with the maximum and minimum ratios observed between the respective variables.

If we consider *u1*, *u2*, *u3* and *u4* as the weights assigned to outputs 1, 2, 3 and 4, respectively, the mathematical expressions stated above, reflect the weight restrictions we developed for our DEA model:

(1) $4{,}19 \leq u1/u2 \leq 294{,}33$

(2) $1{,}26 \leq u1/u3 \leq 8979{,}64$

(3) $1{,}95 \leq u1/u4 \leq 1774{,}38$

(4) $0{,}03 \leq u2/u3 \leq 192{,}65$

(5) $0{,}06 \leq u2/u4 \leq 73{,}06$

(6) $0{,}04 \leq u3/u4 \leq 445{,}37$

In this respect, we have used a benefit-of-the-doubt DEA model with restrictions in the form of trade-offs, as proposed by Podinovski (2004) and explained above.

With the objective of assessing each countries' effectiveness, we used the Efficiency Measurement System (EMS) software, version 1.3.0, with a Constant Returns to Scale (CRS) assumption and an output orientation. This is not very common to find in literature, since most of the published papers that use the benefit-of-the-doubt approach, follow an input orientation. However, and having in mind that our study is in the healthcare context where the ultimate goal is to improve the outcomes, this choice seems to be more adequate for our DEA model. Zanella *et al.* (2013) is a clear example of a paper with this same perspective.

3.2 DATA AND EFFECTIVENESS RESULTS

The data used in this study relates to the performance of countries in what refers to Tuberculosis prevention and control. All the data is from the year of 2013, except for RR-/MDR-TB data. In this case, the values used are from the year of 2012 as data from 2013 were not available. Among the 194 countries and territories that report information to the WHO, the selection of countries to integrate in this study sample, followed two inclusion criteria:

1. Availability of information for the year 2013 in the WHO Tuberculosis Report of 2015;
2. Having treated at least 30 cases of each type (i.e. new and relapsed cases of TB; previously treated (excluding relapses) cases of TB; HIV-positive TB cases; RR-/MDR-TB cases).

Following these criteria, we excluded all countries with missing values on the reports and those with less than 30 cases of each type. The application of these criteria resulted in the selection of 33 countries, as shown in the table 3, below.

Table 3: Number and type of TB cases treated by each of the 33 countries included in the study

	New and relapsed TB cases (2013)	*Previously treated TB cases, excluding relapses (2013)*	*HIV-positive TB cases (2013)*	*RR-/MDR-TB cases (2012)*
	Cohort (n. º)	Cohort (n. º)	Cohort (n. º)	Cohort (n. º)
Argentina	8474	782	554	89
Bangladesh	184077	6327	68	505
Belarus	3034	222	138	2509
Botswana	7254	124	4083	63
Brazil	76543	6945	9460	825
Burundi	7547	80	977	36
China	841999	7847	4649	1906
Colombia	11902	708	1489	99
Dominican Republic	2898	162	263	100
Georgia	3098	779	31	623
Guatemala	2978	36	243	39
Haiti	16557	483	2857	62
India	1243	171712	44027	14051
Indonesia	325582	1521	2438	432
Iran (Islamic Republic of)	10884	305	284	62
Kazakhstan	14456	464	340	7213

Kenya	81255	8445	31755	197
Lesotho	9119	1619	7683	146
Malaysia	23346	654	1510	74
Mexico	20708	638	1230	133
Namibia	8418	2192	4343	208
Nigeria	91997	8404	7481	154
Pakistan	289376	7217	37	858
Peru	17265	2802	1016	1122
Republic of Moldova	3889	357	247	856
Romania	15188	925	250	638
Rwanda	5701	278	1448	58
South Africa	321087	18292	191189	8084
Tajikistan	5263	812	122	535
Turkey	13170	239	32	291
Uganda	44605	2572	16762	41
Ukraine	29726	9149	7553	5556
United Republic of Tanzania	64053	1679	20320	45
Mean	77657	8023	11057	1443
Standard Deviation	164644	29662	33775	3021
Minimum	1243	36	31	36
Maximum	841999	171712	191189	14051

All the presented countries are low and middle income countries, among which, 10 (Bangladesh, Brazil, China, India, Indonesia, Kenya, Lesotho, Namibia, Nigeria and Pakistan) are HBC. In terms of the six WHO regions, our sample has the following distribution:

- Africa Region: Botswana, Burundi, Kenya, Lesotho, Namibia, Nigeria, Rwanda, South Africa, Uganda and Tanzania;
- Americas Region: Argentina, Brazil, Colombia, Dominican Republic, Guatemala, Haiti, Mexico and Peru;
- Eastern Mediterranean Region: Iran (Islamic Republic of) and Pakistan;

- Europe Region: Belarus, Georgia, Kazakhstan, Republic of Moldova, Romania, Tajikistan, Turkey and Ukraine;
- South-East Asia Region: Bangladesh, India and Indonesia;
- Western Pacific Region: China and Malaysia.

In our opinion, having this diversified distribution in our sample assumes substantial importance, as it allows us to analyze the relative performance of some of the countries that most contribute to the high number of TB cases reported, and at the same time compare them with others that are not so affected by this disease in order to identify the best practices. The imposition of these criteria to select the countries, provides assurance regarding the robustness of the data and consequently of the results we obtain.

Considering all the information provided above, we are now going to present table 4 with the data regarding treatment success rates (%) for some of the countries studied:

Table 4: Data used in the DEA model regarding treatment success rates

Countries	*New and relapses, 2013*	*Previously treated, excluding relapses, 2013*	*HIV-positive TB, 2013*	*RR-/MDR-TB, 2012*
	Output 1	Output 2	Output 3	Output 4
Argentina	51	40	32	34
Bangladesh	93	86	75	72
Belarus	87	71	65	54
Botswana	73	60	71	70
Brazil	72	38	46	51
Burundi	91	84	87	92
China	95	90	82	42
Colombia	71	42	45	48
Dominican Republic	83	51	65	72
Georgia	80	69	68	48
*Guatemala**	84	67	62	69
*Haiti**	81	75	71	76

India	88	66	76	46
Indonesia	88	64	49	54
Iran (Islamic Republic of)	87	82	66	48
Kazakhstan	89	63	59	73
*Kenya**	86	78	79	83
*Lesotho**	70	62	66	64
Malaysia	76	46	51	30
Mexico	80	55	48	74
*Namibia**	86	71	81	68
*Nigeria**	86	83	80	62
Pakistan	93	80	81	71
*Peru**	79	59	57	60
Republic of Moldova	80	39	52	59
Romania	85	45	58	34
Rwanda	85	75	76	98
South Africa	78	69	76	49
Tajikistan	88	82	66	66
Turkey	86	38	53	66
Uganda	75	67	73	80
Ukraine	71	55	44	34
United Republic of Tanzania	91	79	72	73
Mean	82,06%	64,58%	64,61%	61,21%
Standard deviation	8,87%	15,56%	13,54%	16,81%
Maximum	95%	90%	87%	98%
Minimum	51%	38%	32%	30%

By analyzing this table, it is possible to realize the great discrepancies existent between the countries. The fact that Argentina has a treatment success rate for new and relapsed cases of just 51% when China has 95% and the mean is 82,06%, indicates that several gaps still need to be filled and more effective strategies need to be established.

With regards to treatment success among previously treated patients, excluding relapses, the differences are accentuated and the scenario is even less positive. Here, the mean is just 64,58%. A number far from WHO's target of 85%. Moreover, although the maximum value for this rate is very similar to the maximum value observed for the first output (90% for China), when we refer to the minimum value the number is quite discrepant. In fact, Turkey has just 38% of treatment success among these patients.

Specifically speaking about China, as one can tell by analyzing table 4, this country consistently shows high rates of treatment success, and leads the group in what refers to new and relapsed TB cases and previously treated TB cases. According to Lin, Wang, Zhang, Ruan, Chinc & Dyed (2015) several improvements in the Chinese healthcare system were made, as they recognized the impact of TB and the State Council of China implemented a 10-year program in 2001 that expanded services' coverage. This can in fact justify these high success rates. Further information about China's strategies will be provided bellow.

When we turn our attention to the third output, having in mind that Argentina was the country with the lowest treatment success rate in output 1, it is not shocking to verify that the minimum value observed in this output also belongs to this country. Argentina has just 32% of success rate regarding HIV-positive patients with TB, followed by Ukraine with 44%. An interesting fact is that the country with the highest rate of success in the third output is Burundi (82%). However, this high success rate in terms of HIV positive TB cases turns to be not so surprising when we realize that Burundi also shows relatively high success rates in terms of outputs 1 and 2.

In the fourth output is where we can notice a greater difference between countries, with a standard deviation of 16,81%. When focusing on the extreme values, we can compare, for example, Malaysia with a 30% treatment success rate, and Rwanda, which has the highest rate of all countries (98%). There is, therefore, a difference of 68% between these two countries. In general, analyzing the rate's standard deviation for all outputs, the numbers are quite significant, especially when we report to previously treated patients, excluding relapses, and to RR-/MDR-TB patients. This high variation between countries suggests that there is potential for improvement in some countries and that high treatment success rates are achievable. Low rates in treatment success suggest that the patients may not be receiving an adequate treatment and may receive a poor monitorization and control.

Even though this analysis of the summary statistics allows us to have a first idea regarding the countries performance, and considering that trade-offs may occur between the treatment of the four types of patients, we need to undertake an analysis with DEA in order to identify the best practices. Table 5 shows the scores to all 33 countries from the DEA model presented above:

Table 5: DEA effectiveness scores and % contribution of each output to the score

	DMU	*Score*	*Output 1*	*Output 2*	*Output 3*	*Output 4*
1	Argentina	54,41%	95%	0%	0%	5%
2	Bangladesh	100,00%	90%	4%	0%	6%
3	Belarus	92,58%	96%	0%	0%	4%
4	Botswana	80,71%	56%	1%	43%	0%
5	Brazil	76,95%	95%	0%	0%	5%
6	Burundi	100,00%	40%	9%	31%	20%
7	China	100,00%	72%	16%	12%	0%
8	Colombia	75,74%	95%	0%	0%	5%
9	Dominican Republic	89,85%	92%	0%	0%	8%
10	Georgia	85,07%	95%	0%	1%	4%
11	Guatemala*	90,63%	92%	0%	0%	8%
12	Haiti*	88,45%	75%	17%	0%	8%
13	India	93,07%	95%	0%	1%	4%
14	Indonesia	93,53%	96%	0%	0%	4%
15	Iran (Islamic Republic of)	92,25%	78%	18%	0%	4%
16	Kazakhstan	95,95%	92%	0%	0%	8%
17	Kenya*	94,10%	91%	0%	0%	9%
18	Lesotho*	76,42%	57%	1%	42%	0%
19	Malaysia	79,90%	100%	0%	0%	0%
20	Mexico	87,03%	91%	0%	0%	9%
21	Namibia*	93,77%	57%	1%	42%	0%
22	Nigeria*	93,61%	50%	12%	37%	1%

23	Pakistan	100,00%	91%	0%	3%	9%
24	Peru*	84,79%	95%	0%	0%	5%
25	Republic of Moldova	85,65%	95%	0%	0%	5%
26	Romania	89,34%	100%	0%	0%	0%
27	Rwanda	97,61%	61%	2%	1%	36%
28	South Africa	86,32%	56%	1%	43%	0%
29	Tajikistan	94,56%	77%	17%	0%	6%
30	Turkey	92,23%	95%	0%	0%	5%
31	Uganda	83,90%	43%	1%	33%	23%
32	Ukraine	74,82%	97%	0%	0%	3%
33	United Republic of Tanzania	98,06%	92%	0%	0%	7%

For a better understanding of these results, we now present the descriptive statistics:

Table 6: Descriptive statistics of the scores and % contribution of each output to the score

	Score	*Output 1*	*Output 2*	*Output 3*	*Output 4*
Mean	88,52%	82,00%	3,00%	9,00%	6,00%
Maximum	100,00%	100,00%	18,00%	43,00%	36,00%
Minimum	54,41%	40,00%	0,00%	0,00%	0,00%
Standard deviation	9,62%	18,43%	5,88%	16,08%	7,37%

Regarding table 5, we can observe that only 4 countries (Bangladesh, Burundi, China and Pakistan) are effective, 20 countries have scores higher than 85% and just 1 has a score lower than 70%. The average of the effectiveness score is 88,52%, which demonstrates margin for improvement but at the same time validates the efforts that have been undertaken in some countries to pursue effectiveness in TB prevention and control. The standard deviation is 9,62%, which indicates that there are some differences between the performance of the countries. However, this value does not translate the gap that exists between some of the countries, which is larger and demands effective changes in countries programs. That difference is more perceivable when one focuses the attention on the minimum and maximum value of the score. For example, Argentina has a score of 54,41%, which is 34,11% lower than the average score of all countries. This difference makes clear that great changes need to be implemented, the reasons behind the gap need to be identified and Argentina must learn from effective countries.

In order to fully understand countries performance, we need to analyze the contribution of each output to the overall effectiveness score. The last four columns of Table 6 present the optimal share of contribution of each output to the score. It is important to emphasize one aspect. The shares of contribution presented in table 5 are rounded values. Whilst in some cases, we can observe a null share of weight attributed to some outputs, this does not correspond to zero weight. In fact, this corresponds to a weight which is very close to zero. Similarly, when a 100% contribution is attributed to some outputs, this corresponds to a contribution that is close to 100%.

Therefore, in terms of optimal weight distribution, we can see different scenarios among the 33 countries and by analyzing them we can extract valuable information about the strategies implemented by countries. The first output, which has a mean of contribution of 82%, is, clearly, the one with more representation in the effectiveness score. We can observe that all countries benefited from the attribution of the largest share of weight to the first output, which is not surprising, given that, except for Burundi, Uganda and Rwanda, the best treatment success rate for all countries is for new and relapsed cases. At the extreme, we can observe two countries (Malaysia and Romania) that have actually benefited from the attribution of almost the totality of the weight to the first output. Generally, while Malaysia and Romania benefited from this weight distribution, others benefited from the distribution of the weight into two or three outputs, and only 4 countries benefited from the distribution through all four.

Concerning the second output, this is the one with the lowest mean of contribution of all 4 outputs, with just 3%. In addition, 20 countries assigned it a close to zero weight and the remaining countries have put between 1% and 18% of the weight on this output. With this, output 2 appears to be one of the less contributive to the effectiveness score alongside with output 4. In the case of the fourth output, 8 countries put a weight close to zero on it and the other countries benefited from the attribution of a weight between

1% and 36%. Among this last group, 23 countries chose to put less than 10% of their weight into RR-/MDR-TB cases.

With regards to the third output, 21 countries assigned a close to zero weight to it and 4 countries assigned less than 10% of the weight to this output. This situation is expected since we know that the choice of the weights follows the scheme that most benefits the countries, and, in the case of HIV-positive TB cases, the treatment success rates are lower than in other cases. However, 7 countries have assigned more than 30% of their weight to this output, which are the countries with highest treatment success rates for this category of patients (see for example Burundi) and countries that have divided the weight more equally through the four outputs in our DEA model (see for example Uganda).

When we analyse the optimal share of contribution of the outputs chosen for each country, it is more prudent to take conclusions about the non-effective countries rather than the effective ones. This occurs because this weight distribution is the one that maximizes their effectiveness score and if they are not effective in this scenario, they will not be in any different one. However, one cannot have this certainty about effective countries. For the effective countries, there is a possibility of existing a different weight distribution that produces the same effectiveness results and, if this is the case, the interpretation of the relative importance of each output can assume completely difference values. Cooper, Ruiz & Sirvent (2007) corroborate this by affirming that, for the units that score 100%, we may have different optimal weights associated with the performance score of a given unit and this may provide very different insights into the role played by the variables used in the performance assessment.

In what refers to the effective countries, table 8 allows us to see that China and Bangladesh assume the strongest positions as benchmarks, since they serve as an example for 20 different non-effective countries. After them, Burundi is a reference for 14 countries and Pakistan for only 2. The reason for this situation relates to the weight scheme that these countries have used. Countries with unusual weight distribution tend to be the reference for a low number of non-effective countries. The following table presents the peers (effective countries that act like benchmarks) and the lambdas (weight of each peer) for every country:

Table 7: Summary of Benchmarks (peers and lambdas)

DMU	*Benchmarks*
Argentina	Bangladesh (0,63) China (0,37)
Bangladesh	20
Belarus	Bangladesh (0,51) China (0,49)
Botswana	Burundi (0,89) China (0,11)
Brazil	Bangladesh (0,72) China (0,28)
Burundi	14
China	20
Colombia	Bangladesh (0,63) China (0,37)
Dominican Republic	Bangladesh (0,69) Burundi (0,31)
Georgia	Bangladesh (0,26) China (0,52) Pakistan (0,21)
*Guatemala**	Bangladesh (0,84) Burundi (0,16)
*Haiti**	Bangladesh (0,31) Burundi (0,69)
India	Bangladesh (0,02) China (0,78) Pakistan (0,20)
Indonesia	Bangladesh (0,45) China (0,55)
Iran (Islamic Republic of)	Bangladesh (0,32) China (0,68)
Kazakhstan	Bangladesh (0,88) Burundi (0,12)
*Kenya**	Bangladesh (0,20) Burundi (0,80)
*Lesotho**	Burundi (0,83) China (0,17)
Malaysia	China (1,00)
Mexico	Bangladesh (0,46) Burundi (0,54)
*Namibia**	Burundi (0,61) China (0,39)
*Nigeria**	Burundi (0,48) China (0,52)
Pakistan	2
*Peru**	Bangladesh (0,92) China (0,08)
Republic of Moldova	Bangladesh (0,80) China (0,20)
Romania	China (1,00)
Rwanda	Burundi (1,00)
South Africa	Burundi (0,30) China (0,70)
Tajikistan	Bangladesh (0,92) China (0,08)
Turkey	Bangladesh (0,88) China (0,12)
Uganda	Burundi (1,00)
Ukraine	Bangladesh (0,06) China (0,94)

United Republic of Tanzania	Bangladesh (0,90) Burundi (0,10)

As we mentioned before, China and Bangladesh are the strongest benchmarks (these countries work as benchmark to a large number of non-effective countries) and for that reason it is important to identify and understand their strategies, practices and how they overcome their problems, so that other countries can learn from them. In the case of China, there were several improvements and new strategies implemented that can justify this performance. Primarily, these results can be attributed to the expansion to the entire country of the DOTS program, implemented in 2001 by the Chinese Center for Disease Control and Prevention (Lin *et al.*, 2015). By implementing this program, they were able to increase coverage and treatment success, since during the entire course of treatment, the medication is provided and directly observed by a healthcare worker. With this, patients' adherence to the treatment was significantly improved. Moreover, according to WHO (2013), in China, the cost of TB treatment, provided as a public service, is covered by domestic healthcare budgets, often supplemented by international grants or loans. Olson, English & Claiborne (2014) refer that MDR-TB is covered by medical insurance for all patients and close to 70% of the entire cost is returned to the patient. This helps to reduce the financial barriers and financial burden of the disease which could lead to giving up treatment.

In addition to all this, several other improvements in the Chinese programs are worth to be pointed out. Indeed, the Chinese government has been investing in diagnostic technologies and scientific research to contribute to the development of new drugs and drug regimens. Cell phones have been used in a pilot study to alert or remind patients to take medicine and to convey information about the side effects of treatment to physicians (Olson *et al.*, 2014).

In the case of Bangladesh there are also numerous policies and events that may justify the good performance of this country. This country is, like China, under the DOTS strategy, which started covering 99% of all population in 2003. In 2010, a five-year cooperative agreement led by the United States Agency for International Development, supported a project called TB CARE II Bangladesh financed by the Global Fund and the Government of Bangladesh. With this project, Bangladesh could fill its gaps with major emphasis on universal and early access to TB services, Programmatic Management of Drug Resistant TB and health systems (Government of the People's Republic of Bangladesh, 2013). Moreover, laboratories quality assurance and support systems at all levels, were also a concern. In fact, the National Tuberculosis Control Program (NTP) has been improving since it was first implemented and preserves high treatment success rates, having achieved WHO's target of 85% treatment success from 2003 until now.

Since Bangladesh is a low-income country, an important problem to address is the financial burden of TB. Intending to overcome this issue, according to the Annual Report of Tuberculosis Control in Bangladesh from 2013, the NTP guaranteed free diagnostic and treatment services in all Upazila Health Complex, 44 Centers for Disease Control, 12 Chest Disease Hospitals, workplaces, prisons, etc. All these strategies made a significant difference on Bangladesh's approach to TB patients, and that difference is shown by its performance results presented above.

In the case of Burundi, the success achieved in the treatment of HIV-TB cases (where the country achieves the highest treatment success rate) can also be explained by some important policies and strategies that were implemented. Even though Burundi has reduced financing capacity, the money donated by the Global Fund to Fight Acquired Immunodeficiency Syndrome (AIDS), Tuberculosis and Malaria and other partners, gave them the opportunity to fill the gaps in the existing programs and improve results. Indeed, the United States Department of State (2015), emphasizes that the following strategies have contributed for the improvement of TB results in Burundi: systematic HIV testing among TB patients through the integration of HIV testing in all centers of TB care: surveillance of HIV sero-prevalence among TB patients; systematic integration of HIV prevention messages in structures for management of tuberculosis; early initiation of antiretroviral therapy for patients on TB treatment; and capacity building in centers for diagnosis and treatment so that they are able to provide quality services with a regular supply of drugs, equipment and consumables necessary for the diagnosis and treatment of co-infected patients.

The last of the effective countries, is Pakistan. Despite this country being a reference (benchmark) for only 2 other countries, its performance score requires attention. In fact, the effectiveness of this country has its foundations in some strategies that were implemented. According to the Global Tuberculosis Report (WHO, 2016), Pakistan has established partnerships between the public and private sectors, which led to the implementation of an active screening for TB in private clinics, private hospitals and laboratories, and guaranteed access to new faster diagnostic tests in private clinics at a low or zero cost. The implementation of this partnerships translated in the increase of the numbers of case notifications and improved patient's monitorization. More specifically, the number of case notifications in the city of Karachi doubled in one year (WHO, 2016).

The treatment success rates for Pakistan are quite balanced. It's highest treatment success rate, like most countries, regards to new and relapsed cases of TB. The HIV-positive TB cases has 81% treatment success and previously treated TB cases, excluding relapses has 80%. The lowest treatment success rate refers to RR-/MDR-TB cases. This is due to a severe problem with resistant TB, as high levels of ofloxacin resistance were found in this country (WHO, 2016). According to Metzger, Baloch, Kazi1 & Bile (2010), additional strategies funded by global and national sources, have contributed to the significant improvement in case detection and to the treatment success rates outlined above. These authors identify improvements in surveillance and laboratory network and improvements in patients' follow-up and treatment modalities as the most significant changes in Pakistan's TB control program. They explain that

> *"a 5-year plan was devised leading to universal DOTS coverage in the public sector towards the end of 2005. The funding was lined up efficiently by the federal Ministry of Health and provincial Departments of Health, with responsibilities delineated and TB control activities integrated into the primary health care system."*

(Metzger *et al.*, 2010: 49)

Despite Rwanda not being considered one of the effective countries, the treatment success rate of this country regarding RR-/MDR-TB deserves some attention. The treatment of this category of patients suffered several alterations and because of that Rwanda shows the highest treatment success. Rwanda recognized that there were in the country high numbers of cases of MDR-TB and implemented several improvements to address this problem, which translated in better results. Specifically speaking, Rwanda went from a "twice a week" treatment in 1990, to a daily treatment in 2006. The previous intermittent intake of medicines resulted in the appearance of MDR-TB cases and created the need of effective strategies. In 2000, the Rwandan government created a plan with the primary objective of rapidly transforming Rwanda into a middle-income country, in which health was identified as a key pillar in the government's vision for economic development and poverty reduction (United Nations Office for Project Services, 2014). With this program, it was possible to start undertaking home visits for patients lost to follow-up and to improve treatment surveillance and monitorization.

Regarding the information provided by table 8, it is important to clarify how one should interpret the values presented for each of the non-effective countries. Indeed, the name of the country that is presented before the parenthesis is the peer, or in other words, the effective country that the non-effective country should have as an example to improve its own results. The number between parenthesis is the lambda (λ), or the coefficients that should be applied to the output values of each peer in order to estimate the target value for the non-effective country. In fact, with this information, DEA allows us to analyze which countries serve as benchmark for the non-effective ones, the weight of that influence and which effective countries are the strongest and serve as benchmarks for a larger group. Moreover, one can easily calculate the targets for each non-effective country.

The calculation of targets for non-effective countries is an interesting tool. Argentina has an improvement score of 183,79%, obtained by calculating the mathematical inverse of its effectiveness score presented in table 6. This score means that Argentina should be able to improve its performance by 83,79%. However, one does not know which values should the treatment success rates for each type of TB assume. This is only possible by calculating the targets for each non-effective country, as shown by the following formula. Consider that: "T_{x1}" is the target for the treatment success rate for new and relapsed cases (output1) for country *x*; "B_1" is the treatment success rate of peer 1; "B_2" is the treatment success rate of peer 2; λ_1 is the weight of peer 1; λ_2 is the weight of peer 2.

$$T_{x1} = (B_1\,\lambda_1) + (B_2\lambda_2)$$

Following this method, table 8 shows the targets for each non-effective country:

Table 8: Targets for non-effective countries

DMU	*Output 1*	*Output 2*	*Output 3*	*Output 4*
Argentina	94%	87%	78%	61%
Belarus	94%	88%	78%	57%
Botswana	91%	85%	86%	87%
Brazil	94%	87%	77%	64%
Colombia	94%	87%	78%	61%
Dominican Republic	92%	85%	79%	78%
Georgia	93%	86%	79%	55%
Guatemala	93%	86%	77%	75%
Haiti	92%	85%	83%	86%
India	95%	88%	82%	48%
Indonesia	94%	88%	79%	56%
Iran (Islamic Republic of)	94%	89%	80%	52%
Kazakhstan	93%	86%	76%	74%
Kenya	91%	84%	85%	88%
Lesotho	92%	85%	88%	84%
Malaysia	95%	90%	82%	42%
Mexico	92%	85%	81%	83%
Namibia	93%	86%	85%	73%
Nigeria	93%	87%	84%	66%
Peru	93%	86%	76%	70%
Republic of Moldova	93%	87%	76%	66%
Romania	95%	90%	82%	42%
Rwanda	91%	84%	87%	92%
South Africa	94%	88%	84%	57%
Tajikistan	93%	86%	76%	70%
Turkey	93%	86%	76%	68%
Uganda	91%	84%	87%	92%
Ukraine	95%	90%	82%	44%
United Republic of Tanzania	93%	86%	76%	74%

With this information, and the information regarding their specific peers, each country can plan strategies in order to achieve the specific values proposed as target for each of the outputs. The success rates observed for some countries are already close to the proposed targets, and therefore only small improvements are necessary. Others, like Argentina or Brazil, are far from their targets and because of that, deeper changes are needed to fill the gaps. Having effective countries as reference for reconsidering their own practices is a useful strategy that can lead them to effective results. For example, Argentina and Brazil can develop strategies based on the best practices observed in Bangladesh and China, which we discussed previously.

4. CONCLUSION

Regarding the seriousness of the world situation and the worrying spread of TB, public policies that can effectively improve the quality of life of the population represent an urgent need. For the structures responsible for national TB programs, it is necessary that effective actions are implemented to ensure detection, treatment and prevention of TB. Despite all the efforts made and the several strategies undertaken in TB prevention and control, this disease stills poses a massive health problem with huge social and economic impacts. The WHO (2016) points to 6.1 million new TB cases in 2015 and makes clear that gaps in financing, prevention, treatment monitorization and control must be filled.

To the best of our knowledge, there are no contributions exploring countries effectiveness in TB prevention and control through DEA analysis. Consequently, it is our aim that the present study makes a significant contribution to the knowledge in this area. With this intention, we have proposed a DEA model to analyze the performance of 33 low and middle income countries regarding the treatment success rates in TB prevention and control. In this model, we have included one single unitary input and 4 outputs.

Despite the practical and relatively simple use of DEA, this study faced several obstacles and challenges through its development. Data unavailability for more recent years and the existence of missing values for a high number of countries in WHO's reports, represents, probably, the most relevant challenge. In fact, information about treatment success rates is missing for numerous countries for the year of 2013 and those who have information, sometimes it does not comprehend all types of TB or patients' categories. Moreover, information available for most of the countries, covers just a single year or, when it covers more than one year, it is not for consecutive years. Because of this, we were unable to perform a dynamic analysis of the performance of countries but we believe that the present DEA model allowed some relevant findings. We also advise some caution in the interpretation of the results for Guatemala, Haiti, Kenya, Lesotho, Namibia, Nigeria and Peru (countries marked with the sign * in Tables 6 and 8) as for these countries output 1 does not include the relapsed cases. These cases are accounted in output 2. Considering that none of these countries was considered effective, that means that their TB treatment success rates did not impact the effectiveness scores of the other countries. However, considering that the prognosis of treatment for new and relapsed cases is better that for previously treated TB cases, excluding relapses, it is likely that the effectiveness scores for these countries are overestimated.

Other important challenge we faced relates to the selection of the weight restrictions imposed in the DEA model. In fact, one needs to consider the possibility that the selected weight restrictions may benefit the effective countries and, by imposing a weight scheme far from the real priorities of the countries, we might make them look effective when in reality they are not. Although we have pointed above several studies that have used weight restrictions, further investigation about this issue needs to be done in order to guarantee meaningful conclusions.

Despite the exploratory nature of this study, there are some important conclusions that need to be highlighted. Among the 33 countries, China, Bangladesh, Burundi and Pakistan were considered effective in TB prevention and control. Although the standard deviation of the performance scores does not constitute a very surprising number, the analysis case by case showed significant variation in some countries. This indicates that countries could make better use of their resources and consequently achieve better results. Furthermore, our study allowed the identification of the benchmarks and some of their best practices, and helped establish specific targets so that the non-effective countries can plan strategies in order to achieve those targets. Regarding the identification of the specific causes behind poor performance and the reasons why specific strategies are not being effective in TB prevention and control, deeper investigation deserves to be done.

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