Technical Efficiency of healthcare systems: a response to pandemic mortality

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Abstract

The Covid-19 pandemic caused an unusual population mortality rate. This paper aims to determine a causal relationship and its incidence between the Technical Efficiency (TE) of healthcare systems and the Covid-19 mortality rate. Using the Data Envelopment Analysis (DEA) methodology and the OLS, GLS and 2SLS adjustment methods, in 108 countries grouped according to per capita health expenditure, it was found that a 1% increase in the TE of the healthcare systems of the analyzed countries reduces the number of deaths from Covid-19 by between 61 and 127 per hundred thousand inhabitants, concluding that the efficiency of expenditure was transcendental in the prevention of mortality caused by the pandemic.

Keywords: Covid-19; efficiency; public spending; mortality; public health.

1. INTRODUCTION

In early 2020, humanity faced the COVID-19 pandemic, one of the most significant challenges of recent decades, making it necessary to build resilient, flexible and adaptable structures with institutions that would provide an effective and efficient response while being able to overcome traumatic situations, such as the one generated by the virus, with the most negligible social impact. On March 11, 2020, the World Health Organization (WHO) declared a global pandemic when a highly dangerous transmission of the SARS-CoV-2 virus became evident (Pan American Health Organization [PAHO, 2021]). Control measures were the primary basis for prevention: reduction of its spread through hand hygiene and when coughing, standard contact and airborne transmission precautions, and establishing of isolation measures.

At the end of April 2020, more than 3.1 million cases and 217,132 deaths were reported worldwide. By August, these figures had reached 21.1 million cases and 750,660 deaths. In April 2021, the number of infections was 147.2 million and 3.1 million deaths. In May of the same year, the figures increased alarmingly, with nearly 176 million cases worldwide and almost 4 million deaths. These figures show a highly transmissible infectious process, easily transmitted by nasal or oral particles, which brought the planet to a standstill (see Table 1).

Table 1. Total cases and deaths due to Covid-19 by region (May 2021)

Region	*Cases*	*Cases per 100,000 inhab.*	*Deaths*	*Deaths per 100,000 inhab.*
Africa	5 087 990	391	135 047	10
North America	34 720 246	9 645	622 967	173
Latin America and the Caribbean	35 248 418	5 595	1 213 426	192
Asia	38 427 004	937	536 011	13
Europe	53 609 712	7 344	1 125 119	154
Middle East	9 126 481	2 226	160 297	39
Oceania	78 099	186	1 387	3
World total	176 297 950		3 794 254	

Source: Compiled by the author based on BBC (2021).

Against this background, there was widespread ignorance about the causes, consequences and, above all, how health institutions responded and offered the necessary reassurance to the population. The scientific community warned that the presence of pandemics will be more frequent and their consequences more devastating, with elevated levels of contagion and higher mortality (IPBES, 2020; Han *et al.*, 2015 and 2016; Menachery *et al.*, 2015; Allen *et al.*, 2017). It is estimated that about 1.7 million undiscovered viruses exist, of which more than 850,000 are capable of human transmission (IPBES, 2020). A bleak future seems imminent, making it necessary to direct efforts towards prevention in the field of health.

The healthcare service understood as a right, has constituent elements that the State should guarantee in order to satisfy one of the basic needs, as well as social justice and equality (Vanhulst, 2015). In this respect, the WHO and the PAHO have developed a series of indicators that determine minimum thresholds for healthcare services to correspond with effectiveness in care. The most usual are current public expenditure on health per capita and out-of-pocket expenses.[1] It has also been found that for every thousand inhabitants, 2.28 health professionals and 2.4 beds are required in the health system in order to provide a minimum coverage of 80% of care (WHO, 2006).

Table 2 shows that Argentina and Brazil have the highest per capita health spending in South America. In contrast, Ecuador, Paraguay and Venezuela show a higher percentage of out-of-pocket spending, although this has decreased in Venezuela.

Table 2. Use of health resources by country and by year in South America

Countries	*Out-of-pocket health care spending as % of total spending*			*Current health expenditure per capita in ppa*		
	2013 %	*2014* %	*2015* %	*2013* $	*2014* $	*2015* $
Argentina	19	19	18	1 287.70	1 268.30	1 389.80
Bolivia	30	26	23	348.20	384.90	445.80
Brazil	22	21	20	1 275.60	1 365.30	1 391.50
Colombia	14	15	18	765.40	856.00	852.80
Chile	32	32	31	1 677.70	1 774.10	1 903.10
Ecuador	40	40	42	942.00	994.40	980.20
Paraguay	38	36	35	593.40	682.90	724.30
Peru	31	28	31	572.60	621.80	671.00
Uruguay	17	16	16	1 690.80	1 754.10	1 747.80
Venezuela	35	31	28	641.60	640.10	579.40

Source: Compiled by the author based on PAHO (2020).

Nevertheless, efficiency parameters are not established; instead, inefficiencies of between 20 and 40% of the resources allocated to the health field have been identified (WHO, 2010).

Efficiency should be conceived as the capacity to produce with limited resources measured in the amount of goods and services that can be obtained for each unit of resource used (Mankiw, 2012). Meanwhile, Hurley (2000) indicates that it is essential to discuss the efficiency of a service, good or activity if an explicit objective has been articulated against which this efficiency can be evaluated.

Farrell (1957) states the need to measure production efficiency in a given industry to understand how much that production unit can increase its product simply by increasing its efficiency without absorbing more resources than it has available.

Hurley (2000) and Cid *et al.* (2016) define TE as that which is achieved by producing a given output with the minimum use of inputs, understood as the adequate and optimal use of resources in production, with various combinations of inputs to achieve a given output. Soto and Casado (2019) contribute by indicating that TE is achieved by obtaining the maximum result from given resources, or that these results are at least as high as the opportunity cost or, if producing the same results, a smaller amount of resources is consumed.

From a sample of 32 public hospitals in Chile from 2011-2013, Santelices (2017) found an average efficiency of 77%. Another sample of 40 units in 2012 reported an efficiency of 86%. In Colombia, Fontalvo (2017) indicates that 12 of the 17 units analyzed present optimal efficiency. Meanwhile, Meza (2018) observed that only 14.5% of the 29 Colombian entities studied were 100% efficient.

Rodriguez *et al.* (2015) measured the TE of four clinics specializing in neurological diseases in Cuba, finding a mean scale efficiency of 66.8% in 2012 and 78.7% in 2013. In Ecuador, Suin *et al.* (2021) found higher TE in the public rather than in the private health system. However, they warn that this could be due to the very nature of the private service reflected in the variables used.

Multinational studies, such as that of Maza and Vergara (2017), which analyze the efficiency of high-complexity hospitals and clinics in Latin America during the period 2010-2011, found that 65% of the units were totally efficient and 48% experienced growth in their productivity due to increases in their efficiency and technological improvements. Sanmartín *et al.* (2019) quantified the relative efficiency of total health spending in 62 countries in Latin America and the Caribbean (LAC) and the Organization for Economic Cooperation and Development (OECD), finding that in 2014, the most efficient countries in LAC were Chile, Cuba, the Dominican Republic, Venezuela and Jamaica, and in the OECD, Japan, Luxembourg and Turkey.

The Inter-American Development Bank (Banco Interamericano de Desarrollo [IDB], 2018), which measures efficiency levels of healthcare systems in LAC and middle-income OECD countries, found that Latin America shows significant variations in terms of efficiency, with Chile being the best-ranked country (eighth place), together with most OECD countries in the top 25%. Meanwhile, another 22 of the 27 countries are located in the bottom half of average efficiency. Bolivia, Ecuador, Guatemala, Guyana, Panama and Suriname were the lowest-performing countries.

Regarding the use of variables in table 3, different studies have employed Data Envelopment Analysis (DEA) in the analysis of TE. This methodology is used with diverse types of data because of its excellent versatility.

Table 3. Variables used when applying DEA in a review of national and multinational literature

	Input	*Output*
Operational variables		
Health personnel	1, 3, 4, 5, 7, 9, 10, 11, 12, 14, 18, 19, 21, 23	
Number of beds	1, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 18, 20, 21, 23	
Administrative personnel	4, 5, 7, 9, 10, 11, 14, 21, 23	
Miscellaneous units	4, 6, 7, 10, 18, 20, 21	
Age-construction-technology	12, 4	
Expenditure		1, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 18, 19, 20, 23
Activities and services		4, 5, 6, 7, 10, 11, 14, 18, 19, 20, 21
Health indicators		3, 4, 8, 13, 22
Hospital stay		7, 9, 13, 15, 20
User satisfaction		18, 21
Hospital occupancy		12, 13
Readmission		20
Administrative variables		
Assets	2, 16, 17	
Cost of sales	2	
Operating expenses	2, 4, 20, 21, 23, 5, 14, 7, 9, 15, 13, 18, 19	
Public expenditure	3, 8, 22	
Revenues		16, 17, 21
Gross profit		16, 2

Source: Compiled by the author based on 1. Barahona (2011); 2. Fontalvo *et al.* (2015); 3. Gómez *et al.* (2019); 4. Peñaloza (2003); 5. Pérez *et al.* (2017); 6. Pinzón (2003); 7. Portillo *et al.* (2018); 8. Sanmartín *et al.* (2019); 9. Martín y Ortega (2016); 10. Paredes y Cutipa (2017); 11. Lau (2017); 12. Maza y Vergara (2017); 13. Perera (2018); 14. Pérez *et al.* (2019); 15. Meza (2018); 16. Fontalvo (2017); 17. Franco y Fullana (2020); 18. Franco y Fullana (2018); 19. Ferrándiz (2017); 20. Vivas (2019); 21. Santelices (2017); 22. BID (2018) and 23. Rodríguez *et al.* (2015).

Against this background, this study aims to determine a causal relationship and the incidence of TE in healthcare systems in their response to and management of mortality caused by the worldwide presence of the COVID-19 pandemic.

In terms of formality, this document is divided into five sections. The first is the introductory section with a review of the literature. The second section explains the methodologies used and a complete reference of the data that served as the basis for the analysis. The third section presents the results obtained and their interpretation and contribution based on the research. The fourth section discusses the results and refers to the limitations and new research alternatives from other perspectives and methodological resources. Finally, the fifth section presents the conclusions of the research.

2. MATERIALS AND METHODS

Technical Efficiency (TE)

The TE of healthcare systems was measured using the DEA, which is a deterministic and non-parametric frontier method widely used due to its versatility in the use of variables, especially when information is scarce and incomplete (Peñaloza, 2003; García, 1997; Martín, 2008; Yates, 1983).

The methodology presented by Farrell (1957) proposes the existence of Decision-Making Units (DMU) and the use of inputs and outputs, creating an empirical production frontier and measuring the distance to the DMU to obtain a relative efficiency measure. Charnes *et al.* (1978 and 1997) construct ratios resulting from the ratio of the weighted sum of the outputs to the weighted sum of the inputs and, pursuant to Paretian criteria, obtain an efficiency value between 0 (zero) or not at all efficient and 1 (one) or totally efficient, giving rise to the DEA, which assumes Consistent Returns at Scale (CRS).

In addition, Charners *et al.* (1978) obtained two more versions of the DEA: the first minimizes the quantity of inputs to obtain the same output (input orientation), and the second, while maintaining the same quantity of inputs, maximizes the output (output orientation). Meanwhile, Banker *et al.* (1984) propose dual models and add a convexity constraint to obtain the DEA with Variable Returns at Scale (VRS). For the analysis in this study, CRS and VRS models were used, with input orientation, whose mathematical expressions are:

CRS model with *input* orientation

$$Min_{\lambda,h,s_i^-,s_r^+}\ \emptyset \qquad (1)$$

S.A.:

$$\sum_j \lambda_j X_{ij} + S_i^- = \emptyset X_{ij0} \qquad \forall i$$

$$\sum_j \lambda_j X_{rj} - S_r^+ = Y_{rj0} \qquad \forall r$$

$$S_i^+, S_r^- \geq 0 \qquad \forall i, \forall j$$

$$\lambda_j \geq 0 \qquad \forall j$$

VRS model with *input* orientation

$$Min_{\lambda,h,s_i^-,s_r^+}\ \emptyset \qquad (2)$$

S.A.:

$$\sum_j \lambda_j X_{ij} + S_i^+ = \emptyset X_{ij0} \qquad \forall i$$

$$\sum_j \lambda_j X_{rj} - S_r^- = Y_{rj0} \qquad \forall r$$

$$\sum_i \lambda_j = 1$$

$$S_i^+, S_r^- \geq 0 \qquad \forall i, \forall j$$

$$\lambda_j \geq 0 \qquad \forall j$$

Where:

S_i^+, S_r^- : slack variables

Φ: Objective function. Efficiency measure

Y_{rj} : i-th output of the j-th DMU

X_{ij} : i-th input of the j-th DMU

Variables used

The information used comes from the open database of the World Bank (2021). Table 4 presents a total sample of 108 countries as DMU, making a distinction by their per capita health expenditure, divided into 40 and 68 countries, respectively, in order to locate each country within its production area. As far as the inputs and outputs are concerned, the variables used are based on those proposed by the IDB (2018) and Sanmartín (2019), highlighting the fact that the number used in each of the calculations considers the formula proposed by Banker *et al.* (1984) to guarantee correct discrimination between each DMU.

$$DMU \geq \max\{inp * out\, ; 3 * (inp + out)\} \qquad (3)$$

Table 4. Variables used when applying DEA in a review of national and multinational literature

DMU	Input variables	Label	Output variables	Label	Number of variables
Countries whose per capita health expenditure exceeds US$500	Health expenditure per capita	i_gastsalpib	Life expectancy at birth	o_esvinacdi	68 ≥ [3 ; 12]
	Health expenditure as % GDP	i_gastsalpcap	Older than 65 years (%)	o_masesycina	
			Child survival rate	o_tassuperv	
Countries whose per capita health expenditure is less than US$ 500	Health expenditure per capita	i_gastsalpib	Life expectancy at birth	o_esvinacdi	40 ≥ [3 ; 12]
	Health expenditure as % GDP	i_gastsalpcap	Older than 65 years (%)	o_masesycina	
			Child survival rate	o_tassuperv	

Source: Compiled by the author based on the World Bank (2021) and the daily update on the progress of the pandemic from the British Broadcasting Corporation (BBC, 2021).

The mathematical models applying DEA are presented as follows:

*dea i*_gastsalpib = o_esvinacdi o_masesycina o_tassuperv, rts(CRS) ort(in) stage(2)

*dea i*_gastsalpib = o_esvinacdi o_masesycina o_tassuperv, rts(CRS) ort(in) stage(2)

*dea i*_gastsalpcap = o_esvinacdi o_masesycina o_tassuperv, rts(VRS) ort(in) stage(2)

Regression analysis

Ordinary Least Squares (OLS), General Least Squares (GLS) and 2-Stage Least Squares (2SLS) were used to determine the relationship between the TE of the countries' healthcare systems and the mortality caused by the COVID-19 pandemic.

OLS -attributable to Carl Friedrich Gauss- is one of the most efficient and popular regression analyses due to its statistical properties and assumptions: homoscedastic variance, explanatory variables not sharing information, and errors not correlated with each other. However, if there is evidence of heteroscedasticity, it should be changed to GLS, which will help to correct the lack of efficiency of OLS estimators (Gujarati and Porter, 2009; Girón, 2017).

Meanwhile, suppose inconsistencies occur due to a probable correlation between the stochastic explanatory variable and the stochastic disturbance term. In that case, instrumental variables can be used and 2SLS, developed by Arnold Zellner and Henri Theil (1962) and Robert Basmann (1957), can be applied. Finally, it is important to mention that GLS will present results similar to those of OLS. 2SLS will do the same if the equation explains all the variability in the data around the mean (Gujarati and Porter, 2009; Girón, 2017).

Variables used

The dependent variable will be the mortality rate caused by Covid-19 and the independent variable will be the TE index of the healthcare systems. In addition, control variables were used (see Table 5).

Table 5. Description of variables used in the regression analysis

Variables	*Label*	*Specification*	*Concept and justification*
Dependent	muecovid	Deaths per Covid	Number of deaths caused by Covid-19 per 100,000 inhabitants
Independent	eftecppcVRS	Technical Efficiency	Input health expenditure per capita and variable returns
	eftecpibVRS	Technical Efficiency	Input health expenditure as % GDP and variable returns
	eftecpibCRS	Technical Efficiency	Input health expenditure as % of GDP and constant returns
Control	denpobl	Population Density	Population divided by km2. Variable justified by the transmission and infection capacity of the virus.
	gasbolsil	Out-of-Pocket Expenditure	Health expenditure through out-of-pocket payments per capita in dollars. Variable that is justified by the population's ability to access care in private healthcare systems.
	crecpib	GDP growth	GDP growth rate in constant 2010 dollars. Variable that is justified as an indicator of a country's economic capacity to face crises.
	desnut	Malnutrition	Percentage of the population whose food intake is insufficient to continuously meet dietary energy needs. Variable that is justified by people's health conditions when facing the virus.
	gini	Gini Index	The extent to which income distribution among individuals or households within an economy deviates from a perfectly equal distribution. A variable that is justified by reflecting the level or index of human development and involves key social factors.

Source: Compiled by the author based on the World Bank (2021).

The mathematical models of the regression are presented as follows:

$$muecovid = \beta_0 + \beta_1 eftecppcvrs + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecpibvrs + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecpibcrs + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecppcvrs + \beta_2 denpobl + \beta_3 gasbolsil + \beta_4 crecpib + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecpibvrs + \beta_2 denpobl + \beta_3 gasbolsil + \beta_4 crecpib + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecpibcrs + \beta_2 denpobl + \beta_3 gasbolsil + \beta_4 crecpib + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecppcvrs + \beta_2 denpobl + \beta_3 gasbolsil + \beta_4 crecpib + \beta_5 desnut + \beta_6 gini + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecpibvrs + \beta_2 denpobl + \beta_3 gasbolsil + \beta_4 crecpib + \beta_5 desnut + \beta_6 gini + \varepsilon$$

$$muecovid = \beta_0 + \beta_1 eftecpibcrs + \beta_2 denpobl + \beta_3 gasbolsil + \beta_4 crecpib + \beta_5 desnut + \beta_6 gini + \varepsilon$$

The models would be interpreted as the relationship between the number of deaths caused by COVID-19 and the technical efficiency of the healthcare systems of the sample countries. Control variables are used to ratify the results obtained.

The control variables used were selected based on what the WHO (2009 and 2017) defines as the Social Determinants of Health by referring to the set of social, political, economic, environmental and cultural factors that exert significant influence on the state of health, omitting those that allude to the health condition per se.

3. RESULTS

Technical Efficiency

In the Appendix, tables A1 and A2 show the TE results of the healthcare systems of 40 and 68 countries, respectively, differentiated by per capita health expenditure, while table A3 shows the countries used as a sample. The first group includes Bangladesh, Djibouti, Samoa, Morocco, Honduras, the Solomon Islands and Vietnam, which maintain a TE of 100%, while Gabon and the Central African Republic are the least efficient.

In group 2, Singapore, Japan and Qatar are 100% efficient; the first two in the three scenarios considered. Meanwhile, Kuwait with 14%, South Africa with 25% and Namibia with 21% are the countries with the lowest resource use efficiency. The values depend on the inputs and methods used (CRS or VRS).

Regression analysis

The results are presented in Table 6 and show an inverse relationship between TE and COVID-19 mortality, except for panel B, whose *t-value* indicates that the results are unreliable. In panel A, in all the proposed scenarios, the results have a significant *t-value* of less than 1%, and although the R2 barely reaches 22%, the relationship between the two variables is reliable. These results are supported and exhibit similar behavior in panel C, which uses the 108 observations; the inverse relationship between the variables is maintained. However, the value of the parameter of the independent variable changes: considering the absolute value, it goes from a minimum of 61.17838 to a maximum of 127.88 depending on the input used for the calculation of the TE and the model used: VRS or CRS.

Table 6. Regression model with Covid-19 deaths as the dependent variable

	Health expenditure per capita	*Health expenditure as % of GDP*	
	VRS model	*VRS model*	*CRS Model*
Panel A: Countries with health expenditure per capita above US$500			
Technical Efficiency	-127.88 ***	-83.72164 ***	-95.27453 ***
	[27.25197]	[30.55511]	[30.18117]
Constant	145.1589 ***	117.9721 ***	120.9956 ***
R2	0.2212	0.0857	0.099
Number of observations	68	68	68
Panel B: Countries with health expenditure per capita below US$500			
Technical Efficiency	-4.820077	5.167789	-8.703761
	[12.19875]	[9.414235]	[9.859381]
Constant	17.47132 **	11.19243	19.62029**
R2	0.0026	0.0032	0.0070
Number of observations	40	40	40
Panel C: All countries			
Technical Efficiency	-71.35872 ***	-61.17838 ***	-65.23424 ***
	[18.52188]	[20.12675]	[30.18117]
Constant	91.40339 ***	86.81011 ***	120.9956***
R2	0.0889	0.0659	0.0607
Number of observations	108	108	108

Note: p-value: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; standard errors in square brackets.

Source: Compiled by the author based on results using STATA.

These deductions were tested using control variables in two scenarios. The first used only three variables: Population Density, Out-of-Pocket Expenditures and GDP Growth. Meanwhile, the Malnutrition and Gini Indexes were added to the second (see Tables 7, 8 and 9). Countries with a per capita health expenditure of less than US$500 have been omitted as they exhibit unreliable results in the relationship between variables.

Table 7 shows the results of the model for the sample of countries with a per capita health expenditure of more than US$500 with the inclusion of the control variables. The dependent and independent variables maintain their inverse relationship, as well as for calculation using OLS, GLS and 2SLS. Panel A shows statistical confidence, although its R2 has been reduced to 15.54. Panel B maintains the inverse relationship between the dependent and independent variables, preserving its statistical significance, and its R2 increases to 29.84. It is important to note that the values of parameter β vary depending on the number of control variables included, with no differentiation between the regression models used.

Table 7. Sample of countries with health expenditure greater than US$500 using health expenditure as % GDP as input

	MCO	*MCG*	*MC2E*
Panel A: 3 control variables			
Technical Efficiency	-97.27008 ***	-97.27008 ***	-97.27008 ***
	[35.57986]	[29.47611]	[35.57986]
Population Density	-0.0065469	-0.0065469 ***	-0.0065469
	[0.0073445]	[0.0023551]	[0.0073445]
Out-of-Pocket Spending	0.0355446 **	0.0355446 **	0.0355446 **
	[0.0177603]	[0.0144314]	[0.0177603]
GDP Growth	-2.029535	-2.029535	-2.029535
	[2.997956]	[2.604703]	[2.997956]
Constant	117.6005***	117.6005***	117.6005***
R2	0.1554		0.1554
Number of observations	68	68	68
Panel B: 5 control variables			
Technical Efficiency	-129.4118 **	-129.4118 **	-129.4118 **
	[57.24287]	[50.64491]	[57.24287]
Population Density	0.0088023	0.0088023	0.0088023
	[0.0757527]	[0.0949092]	[0.0757527]
Out-of-Pocket Spending	0.0123035	0.0123035	0.0123035
	[0.022711]	[0.0144922]	[0.022711]
GDP Growth	-3.01469	-3.01469	-3.01469
	[4.399288]	[4.569196]	[4.399288]
Malnutrition Index	-6.281668 **	-6.281668 **	-6.281668 **
	[2.386539]	[1.813643]	[2.386539]
Gini Index	1.010878	1.010878	1.010878
	[1.127851]	[1.377753]	[1.127851]
Constant	163.9679 **	163.9679 **	163.9679 **
R2	0.2984	0.2984	0.2984
Number of observations	40	40	40

Note: p-value: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; standard errors in square brackets.

Source: Compiled by the author based on results using STATA.

This behavior is maintained when all observations are used and the TE is calculated with health spending as a percentage of GDP and health spending per capita, both with VRS. These values are observed in Tables 8 and 9. The results do not vary. The relationship between the slope and independent variables continues to be inverse and the values maintain their statistical significance in all the proposed scenarios. Finally, it is essential to note that the model's fit improves as the number of observations increases, ending with an R2 of 42.70.

Table 8. Sample with all countries using health expenditure as an input as % GDP

Variables	*MCO*	*MCG*	*MC2E*
Panel A: 3 control variables			
Technical Efficiency	-61.41377 ***	-61.41377 ***	-61.41377 ***
	[21.90137]	[18.52394]	[21.90137]
Population Density	-0.0074658	-0.0074658 ***	-0.0074658
	[0.00643673]	[0.0022019]	[0.00643673]
Out-of-Pocket Spending	0.0516782 ***	0.0516782 ***	0.0516782 ***
	[0.01406]	[0.0166841]	[0.01406]
GDP Growth	-2.156442	-2.156442	-2.156442
	[1.773367]	[1.62062]	[1.773367]
Constant	81.04987 ***	81.04987 ***	81.04987 ***
R2	0.2019	0.2019	0.2019
Number of observations	107	107	107
Panel B: 5 control variables			
Technical Efficiency	-94.82057 ***	-94.82057 ***	-94.82057 ***
	[37.75897]	[36.08694]	[37.75897]
Population Density	0.0188223	0.0188223	0.0188223
	[0.040936]	[0.0366725]	[0.040936]
Out-of-Pocket Spending	0.0147634	0.0147634	0.0147634
	[0.0195646]	[0.0140777]	[0.0195646]
GDP Growth	-6.299436	-6.299436	-6.299436
	[3.834391]	[3.991093]	[3.834391]
Malnutrition Index	-4.118347 ***	-4.118347 ***	-4.118347 ***
	[1.449592]	[1.434888]	[1.449592]
Gini Index	1.198691	1.198691	1.198691
	[0.08835683]	[1.103968]	[0.08835683]
Constant	132.0499 ***	132.0499 **	132.0499 ***
R2	0.4050	0.4050	0.4050
Number of observations	56	56	56

Note: p-value: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; standard errors in square brackets.

Source: compiled by the author based on results using STATA.

Table 9. Regression with all countries using per capita health expenditure as input

Variables	*MCO*	*MCG*	*MC2E*
Panel A: 3 control variables			
Technical Efficiency	-59.39136 ***	-59.39136 ***	-59.39136 ***
	[22.00209]	[17.5452]	[22.00209]
Population Density	-0.0065612	-0.0065612 ***	-0.0065612
	[0.0065141]	[0.0021361]	[0.0065141]
Out-of-Pocket Spending	0.045497 ***	0.045497 ***	0.045497 ***
	[0.013999]	[0.0153225]	[0.013999]
GDP Growth	-2.114709	-2.114709	-2.114709
	[1.782879]	[1.701794]	[1.782879]
Constant	79.9014 ***	79.9014 ***	79.9014 ***
R2	0.1977	0.1977	0.1977
Number of observations	107	107	107
Panel B: 5 control variables			
Technical Efficiency	-96.61758 ***	-96.61758 ***	-96.61758 ***
	[34.58586]	[32.11552]	[34.58586]
Population Density	0.0183775	0.0183775	0.0183775
	[0.0402342]	[0.033232]	[0.0402342]
Out-of-Pocket Spending	0.0103406	0.0103406	0.0103406
	[0.0194206]	[0.0134213]	[0.0194206]
GDP Growth	-7.37595 *	-7.37595 *	-7.37595 *
	[3.714136]	[4.31656]	[3.714136]
Malnutrition Index	-3.186764 **	-3.186764 **	-3.186764 **
	[1.380618]	[1.462169]	[1.380618]
Gini Index	1.249489	1.249489	1.249489
	[0.8674487]	[1.120615]	[0.8674487]
Constant	125.7329 ***	125.7329 **	125.7329 ***
R2	0.4207	0.4207	0.4207
Number of observations	56	56	56

Note: p-value: *** p < 0.01; ** p < 0.05; * p < 0.1; standard errors in square brackets.

Source: compiled by the author based on results using STATA.

4. DISCUSSION

The TE shows values with expected behavior. There is a more significant difference when the calculations are carried out using CRS or VRS models, although this difference is not greater. Likewise, when the input is changed, the results are not subject to significant alterations. In the sample of countries with a health expenditure of less than US$500, Bangladesh is the only one that maintains a TE of 100% in all the proposed scenarios. The same occurs with Singapore and Japan in the sample of countries with a health expenditure of more than US$500.

Meanwhile, in the regression analysis, the tests were performed for the three types of samples using OLS, GLS, and 2SLS, and the results are homogeneous and statistically significant. The independent variable Deaths due to Covid is inverse to the dependent variable TE. However, it is worth mentioning that, for countries with health expenditure below US$500, the deductions are not reliable.

The results finally translate into a 1% increase in the TE of the countries' healthcare systems taken as a sample, which would reduce deaths due to COVID-19 by between 61 and 127 per 100,000 inhabitants. These results are supported when all countries are sampled: the regressor of the independent variable maintains its inverse relationship and statistical significance, which indicates that the values and, above all, the deductions that can be obtained based on these results are statistically reliable.

The results also show the importance of maintaining high percentages of TE to meet the population's needs. Gómez *et al.* (2019) indicate that positive changes in the levels of TE will lead to productivity increases in the operational and financial factors of the national healthcare systems of 28 countries of the European Union.

Similarly, the IDB (2018) suggests that several Latin American countries could significantly improve health output indicators while maintaining their current budget stable. The analysis indicates that, if efficient, the region would lengthen its life expectancy by four years; under-five mortality could be reduced by 10 deaths per 1,000 live births; Disability Adjusted Life Years (DALY) lost due to all causes could be reduced on average by 6.1432 per 100,000 inhabitants; specialized care during childbirth could be improved by 4.4% and DTP[2] immunization rates could reach 96.9%.

Furthermore, the R2 is relatively low and the model cannot adjust to the dependent variable. However, although the model does not reliably explain the variability of the data, the causes of mortality are based on the specific health situations of each person, resulting in the logical value of the R2.

As for the control variables, when only three are used, Out-of-Pocket Expenditures show a direct relationship with deaths due to COVID-19 and their value is reliable. In this case, their behavior could be explained by the fact that a deficient health system causes higher Out-of-Pocket Expenditures. Finally, when five control variables are used, the Malnutrition Index maintains statistical significance, although with an inverse relationship to the dependent variable, which could be explained by health factors specific to each person and the relationship with COVID-19.

Given the lack of complete, updated and relevant data, the study has a major limitation given that there is no quality information available, especially in Latin American and African countries and, in some cases, even in first-world countries. This makes it challenging to work with a larger number of variables to compare results.

By its very essence, the DEA also presents the difficulty of contrasting hypotheses since it does not have statistical characteristics such as the presence of error, translating any deviation from the data into ineffective behavior of the DMU. However, it is a valid method used in scientific research.

As for the regression analysis, working with few observations results in an insignificant R2. The scarce knowledge and heterogeneous nature of the dependent variable means that the model cannot provide a reliable explanation. However, it must be understood that the explained variable will depend on medical factors, which have also failed to provide a conclusive explanation.

In terms of scope, the study does not perform a slacks analysis, so it does not know exactly which variables are a source of inefficiencies. Finally, mortality rates by age group have not been standardized in order to determine the level of response to this condition in each country and to be able to compare them.

5. CONCLUSIONS AND RECOMMENDATIONS

The study established a relationship between deaths from COVID-19 and the TE of healthcare systems. The better the use of available resources, the more prepared countries will be to face situations such as those that occurred in the last two years. The study shows that a 1% increase in the TE of the healthcare systems of the countries analyzed would reduce deaths from COVID-19 by between 61 and 127 per 100,000 inhabitants.

It should also be noted that the diversity of the countries, the structure of the healthcare systems, the physical conditions of the people, the behavior and vertiginous mutation of the virus, as well as the structure and economic development of the States, played a dominant role in the effectiveness of the fight against the pandemic. The main challenge initially was to attenuate and contain the accelerated advance of the epidemic.

Extensive literature indicates that pandemics will continue. There is a high probability that humanity will again face other health emergencies, which are expected to be mostly catastrophic and devastating. Given this scenario, a new approach and orientation of public policies in the field of health economics is necessary, acting from a more proactive viewpoint, preparing and improving the response capacity of healthcare systems in order to face, with minimum impact, the consequences of these new epidemics.

It is important to provide policymakers with the technical tools to help them make decisions that can prevent and correct the consequences of situations such as the presence of COVID-19, especially in terms of the use and destination of capital. It is not only a matter of increasing or correctly allocating more resources to the health field -at least in the first instance-, but also of improving their destination and use.

Efficient spending is therefore essential, not only to guarantee people's right to free access and high levels of healthcare coverage but also to ensure that healthcare services and systems respond in an efficient and timely manner to the needs and requirements of the population, being resilient and managing to overcome adverse and highly vulnerable situations, such as the recent pandemic, with the least possible impact.

It is imperative to start thinking about a new way of taking action. The purpose is not to obtain more available resources but to obtain more of the resources available -especially because of their scarcity as opposed to unlimited needs- by being cautious, pragmatic and flexible in prioritizing spending and allocating resources.

APPENDIX

Table A1. Technical Efficiency calculated by DEA for a sample of countries with per capita health expenditure below US$500

Health expenditure per capita						*Health expenditure as a % of GDP*											
VRS Model						*VRS Model*						*CRS Model*					
Nº	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*
1	BGD	1.00	21	IDN	0.501237	1	BEN	1.00	21	PAK	0.666667	1	BGD	1.00	21	COD	0.556477
2	COD	1.00	22	GMB	0.486177	2	BGD	1.00	22	PHL	0.663285	2	DJI	1.00	22	VNM	0.553968
3	ETH	1.00	23	RWA	0.484095	3	COG	1.00	23	UZB	0.652294	3	COG	0.958463	23	HND	0.484472
4	HND	1.00	24	GTM	0.475864	4	DJI	1.00	24	GTM	0.628013	4	SLB	0.953804	24	MMR	0.480000
5	MAR	1.00	25	BOL	0.472602	5	HND	1.00	25	BOL	0.612948	5	VUT	0.943525	25	SEN	0.467818
6	SLB	1.00	26	BEN	0.455022	6	IDN	1.00	26	MMR	0.566667	6	IDN	0.934921	26	BOL	0.466667
7	VNM	1.00	27	COG	0.441228	7	MAR	1.00	27	SEN	0.500000	7	PNG	0.888586	27	GTM	0.453174
8	WSM	1.00	28	MWI	0.434306	8	PNG	1.00	28	TCD	0.500000	8	BEN	0.849983	28	KGZ	0.380923
9	MDG	0.883558	29	PAK	0.406931	9	SLB	1.00	29	NIC	0.474914	9	BTN	0.800000	29	MDG	0.378319
10	VUT	0.847524	30	CPV	0.403699	10	VNM	1.00	30	COM	0.400000	10	WSM	0.763043	30	TCD	0.373186
11	DJI	0.814815	31	COM	0.402888	11	WSM	1.00	31	MDG	0.400000	11	VEN	0.700000	31	MRT	0.357874
12	HTI	0.763889	32	TCD	0.392405	12	VUT	0.968957	32	MRT	0.400000	12	CPV	0.678261	32	COM	0.354631
13	IND	0.624242	33	KGZ	0.381055	13	BTN	0.944904	33	ZMB	0.400000	13	PHL	0.640792	33	ZMB	0.351267
14	VEN	0.614654	34	PHL	0.326363	14	VEN	0.930648	34	ZWE	0.400000	14	GAB	0.620477	34	NIC	0.344086
15	MMR	0.587900	35	CAF	0.319588	15	CPV	0.800959	35	KGZ	0.393143	15	UZB	0.618773	35	ZWE	0.338463
16	PNG	0.543999	36	MRT	0.303054	16	IND	0.708333	36	NER	0.285714	16	PAK	0.618681	36	RWA	0.276615
17	BTN	0.533545	37	ZMB	0.241849	17	COD	0.666667	37	RWA	0.279762	17	ETH	0.610625	37	HTI	0.250000
18	NIC	0.529080	38	UZB	0.218186	18	ETH	0.666667	38	HTI	0.250000	18	IND	0.600000	38	NER	0.245039
19	NER	0.528055	39	ZWE	0.182251	19	GAB	0.666667	39	MWI	0.222222	19	GMB	0.569080	39	MWI	0.206861
20	SEN	0.519572	40	GAB	0.148198	20	GMB	0.666667	40	CAF	0.181818	20	MAR	0.560000	40	CAF	0.132756

Source: Compiled by the author. DEA results using STATA.

Table A2. Technical Efficiency calculated by DEA for a sample of countries with per capita health expenditures greater than US$500

Health expenditure per capita						*Health expenditure as a % of GDP*											
VRS Model						*VRS Model*						*CRS Model*					
Nº	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*	*Nº*	*DMU*	*Score*
1	BLR	1.00	35	DZA	0.536794	1	JPN	1.00	35	SYC	0.560000	1	QAT	1.00	35	BHR	0.520963
2	CYP	1.00	36	ARM	0.525233	2	QAT	1.00	36	CAN	0.555214	2	SGP	1.00	36	TTO	0.511823
3	GUY	1.00	37	RUS	0.523297	3	SGP	1.00	37	BHR	0.534009	3	THA	0.970276	37	MEX	0.505604
4	JPN	1.00	38	DOM	0.506229	4	LUX	0.997516	38	URY	0.533460	4	RUS	0.929066	38	GNQ	0.497495
5	LKA	1.00	39	LUX	0.495928	5	THA	0.987377	39	TTO	0.514286	5	LUX	0.916618	39	OMN	0.491539
6	SGP	1.00	40	CHE	0.487837	6	RUS	0.933333	40	MEX	0.506667	6	KAZ	0.837292	40	CHE	0.484286
7	MNG	0.991341	41	CAN	0.487635	7	FIN	0.895691	41	IRQ	0.500000	7	LKA	0.836404	41	CAN	0.478369
8	KOR	0.954101	42	MEX	0.484020	8	LKA	0.850952	42	MNG	0.500000	8	LCA	0.834753	42	MNG	0.456093
9	VCT	0.940000	43	QAT	0.482332	9	KAZ	0.844444	43	OMN	0.500000	9	VCT	0.826766	43	IRQ	0.454077
10	BRB	0.906548	44	COL	0.475884	10	LCA	0.841477	44	CUB	0.440840	10	GRD	0.826699	44	CUB	0.429435
11	SLV	0.870330	45	BWA	0.471161	11	GRD	0.833333	45	BHS	0.422222	11	BLR	0.804979	45	DOM	0.419731
12	SRB	0.849233	46	NOR	0.467441	12	VCT	0.833333	46	DOM	0.422222	12	JPN	0.794969	46	BHS	0.419523
13	LCA	0.846154	47	IRL	0.456198	13	BLR	0.809001	47	PAN	0.420075	13	FIN	0.748609	47	PAN	0.403499
14	EGY	0.837402	48	ZAF	0.455135	14	BRB	0.743000	48	TUN	0.406962	14	BRB	0.709832	48	TUN	0.401213
15	THA	0.826425	49	GBR	0.444577	15	IRL	0.711485	49	EGY	0.400000	15	CYP	0.655725	49	SLV	0.396945
16	AZE	0.811917	50	ATG	0.442835	16	ISL	0.688423	50	KWT	0.400000	16	IRL	0.642195	50	EGY	0.393164
17	ISL	0.757264	51	BEL	0.442619	17	NLD	0.684095	51	SLV	0.400000	17	MYS	0.634821	51	KWT	0.387610
18	GRD	0.744957	52	SUR	0.435610	18	AUT	0.682035	52	DZA	0.386435	18	ISL	0.627925	52	DZA	0.379287
19	SWZ	0.737103	53	MYS	0.432998	19	BEL	0.680311	53	GUY	0.377778	19	ATG	0.616007	53	GUY	0.369178
20	GNQ	0.736012	54	BHR	0.427820	20	DEU	0.677795	54	ARG	0.365902	20	SRB	0.608364	54	ARG	0.361029
21	IRQ	0.717020	55	NLD	0.418186	21	FRA	0.676279	55	ARM	0.360000	21	NLD	0.579440	55	ARM	0.359647
22	JOR	0.698689	56	AUT	0.412447	22	CYP	0.675836	56	COL	0.359899	22	AUT	0.579337	56	COL	0.351725
23	KAZ	0.659169	57	URY	0.405119	23	SWE	0.672665	57	SAU	0.343544	23	BEL	0.579250	57	SAU	0.333170
24	FIN	0.653804	58	PAN	0.367756	24	GNQ	0.666667	58	BWA	0.333333	24	DEU	0.574617	58	PRY	0.321894
25	AUS	0.611588	59	OMN	0.365189	25	AUS	0.650260	59	ECU	0.324225	25	KOR	0.571072	59	ECU	0.317984
26	NZL	0.594309	60	DEU	0.352722	26	MYS	0.638355	60	PRY	0.323810	26	SWE	0.561753	60	SUR	0.312252
27	CUB	0.594226	61	BRA	0.337265	27	GBR	0.635608	61	SUR	0.316667	27	AZE	0.560534	61	BRA	0.306841
28	MDV	0.592901	62	SYC	0.332473	28	NZL	0.631800	62	BRA	0.307665	28	AUS	0.556405	62	BWA	0.302364
29	NAM	0.580974	63	IRN	0.305625	29	KOR	0.630692	63	SWZ	0.285714	29	SYC	0.555275	63	IRN	0.252650
30	FRA	0.579516	64	ARG	0.277645	30	ATG	0.627542	64	IRN	0.256429	30	NZL	0.554795	64	JOR	0.242573
31	TUN	0.566695	65	TTO	0.259365	31	NOR	0.625334	65	MDV	0.250657	31	GBR	0.552231	65	ZAF	0.236996
32	PRY	0.551312	66	BHS	0.256988	32	CHE	0.624124	66	JOR	0.250000	32	FRA	0.551783	66	MDV	0.227175
33	SWE	0.545378	67	SAU	0.159971	33	SRB	0.612894	67	NAM	0.250000	33	NOR	0.536154	67	SWZ	0.227095
34	ECU	0.541355	68	KWT	0.140878	34	AZE	0.566667	68	ZAF	0.250000	34	URY	0.521123	68	NAM	0.208603

Source: Compiled by the author. DEA results using STATA.

Table A3. Name and code of sample countries

Country Code	Country name	Country Code	Country name	Country Code	Country name	Country Code	Country name
ARG	Argentina	DEU	Germany	KGZ	Kyrgyzstan	QAT	Qatar
ARM	Armenia	DJI	Djibouti	KOR	South Korea	RUS	Russian Federation
ATG	Antigua and Barbuda	DOM	Dominica	KWT	Kuwait	RWA	Rwanda
AUS	Australia	DZA	Algeria	LCA	Saint Lucia	SAU	Saudi Arabia
AUT	Austria	ECU	Ecuador	LKA	Sri Lanka	SEN	Senegal
AZE	Azerbaijan	EGY	Egypt	LUX	Luxembourg	SGP	Singapore
BEL	Belgium	ETH	Ethiopia	MAR	Morocco	SLB	Solomon Islands
BEN	Benin	FIN	Finland	MDG	Madagascar	SLV	El Salvador
BGD	Bangladesh	FRA	France	MDV	Maldives	SRB	Serbia
BHR	Bahrain	GAB	Gabon	MEX	Mexico	SUR	Suriname
BHS	Bahamas	GBR	Gambia	MMR	Myanmar	SWE	Sweden
BLR	Belarus	GMB	Gambia	MNG	Mongolia	SWZ	Eswatini
BOL	Bolivia	GNQ	Equatorial Guinea	MRT	Mauritania	SYC	Seychelles
BRA	Brazil	GRD	Grenada	MWI	Malawi	TCD	Chad
BRB	Barbados	GTM	Guatemala	MYS	Malaysia	THA	Thailand
BTN	Bhutan	GUY	Guyana	NAM	Namibia	TTO	Trinidad and Tobago
BWA	Botswana	HND	Honduras	NER	Niger	TUN	Tunisia
CAF	Central African Rep.	HTI	Haiti	NIC	Nicaragua	URY	Uruguay
CAN	Canada	IDN	Indonesia	NLD	Netherlands	UZB	Uzbekistan
CHE	Switzerland	IND	India	NOR	Norway	VCT	St. Vincent and the Grenadines
COD	Congo, Democratic	IRL	Ireland	NZL	New Zealand	VEN	Venezuela
COG	Congo	IRN	Iran	OMN	Oman	VNM	Viet Nam
COL	Colombia	IRQ	Iraq	PAK	Pakistan	VUT	Vanuatu
COM	Comoros	ISL	Isle of Man	PAN	Panama	WSM	Samoa
CPV	Cabo Verde	JOR	Jordan	PHL	Philippines	ZAF	South Africa
CUB	Cuba	JPN	Japan	PNG	Papua New Guinea	ZMB	Zambia
CYP	Cyprus	KAZ	Kazakhstan	PRY	Paraguay	ZWE	Zimbabwe

Source: Compiled by the author.

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[1] Out-of-pocket expenditure understood as any expenditure of family resources for the acquisition of goods and services useful for restoring or improving health, which are not covered by the health system (Alvis *et al.*, 2007).

[2] Vaccination against diphtheria, tetanus and pertussis or whooping cough.