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Why Nations Respond to COVID-19 Pandemic Differently? An Undesirable Output Data Envelopment Analysis Model

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Abstract

This study analyzes the efficiency of 122 countries in responding to the COVID-19 pandemic, using an Undesirable Output Data Envelopment Analysis (DEA) model. The research identifies critical factors influencing national efficiency, including testing rates, healthcare infrastructure, and socioeconomic conditions. The study finds a strong correlation between higher testing rates and increased efficiency, underscoring the importance of widespread testing in pandemic management. Developed countries, particularly those with universal healthcare systems, generally exhibited greater efficiency in handling the pandemic compared to their less developed counterparts. These findings highlight the role of robust healthcare systems and strategic investments in public health in enhancing national resilience against global health crises. In addition, the study addresses gaps in the current research by integrating multiple factors and analyzing their collective impact on national responses. The results emphasize the necessity for policymakers to prioritize healthcare infrastructure, expand testing capacities, and ensure universal healthcare coverage to improve pandemic preparedness and response. This research contributes to the ongoing debate on global health security by providing empirical evidence that supports the need for comprehensive strategies to manage future pandemics effectively.

Keywords: COVID-19 Pandemic, Efficiency, Data Envelopment Analysis, Universal Health Care System, OECD, COVID-19 Testing

I. Introduction

Research background

Natural and human-caused events such as famines, global conflicts, and wars, or a combination thereof, can present significant disruptions to society, particularly in areas we rely on without much thought (Bhasin, 2015; Chidozie *et al.*, 2015; Ali & Liu, 2021; Azadi *et al.*, 2023). These events can have long-lasting negative effects on public health systems, personal well-being, and the environment (Zhang & Oh, 2024). Both affluent and developing countries face challenges in managing the stressors brought about by these disasters, which can undermine decision-makers' abilities to respond effectively. The ongoing COVID-19 pandemic has underscored

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these vulnerabilities, prompting critical questions about the factors that influence national responses to such crises (Giménez et al., 2024). Previous outbreaks, including SARS, MERS, H1N1, and Ebola, provide historical context, but the COVID-19 pandemic's scale and impact demand a more comprehensive analysis.

Gap in the Literature

While the COVID-19 pandemic has spurred a vast amount of research, much of it is fragmented and lacks integration. The literature is extensive on specific factors like healthcare capacity, testing rates, and economic resources, but few studies have combined these elements to assess their collective impact on national pandemic responses (Min et al., 2022; Giménez et al., 2024; Zhang & Oh, 2024). Moreover, recent studies relevant to this context are not sufficiently addressed, creating a gap in understanding how these factors interact. This study seeks to fill this gap by applying the Data Envelopment Analysis (DEA) model to assess the efficiency of 122 countries in managing the pandemic. By integrating the latest research findings and addressing this gap, the study aims to contribute to the ongoing debate on global health security and pandemic preparedness.

Aim and Originality of the Study

The primary objective of this research is to identify the key factors that influence the efficiency of national responses to the COVID-19 pandemic. The originality of this study lies in its use of the DEA model to evaluate the efficiency of healthcare systems across different nations, offering empirical evidence that can guide policymakers. This approach not only strengthens the study's relevance by integrating recent empirical data but also positions it as a crucial resource for enhancing public health preparedness. The study provides insights into how robust healthcare systems, testing rates, and other socioeconomic factors impact pandemic outcomes, contributing to the broader understanding of effective response strategies. This paper is organized as follows: Section 2 presents a comprehensive literature review, highlighting prior research and identifying gaps. Section 3 details the methodology used in the study, including the application of the DEA model. Section 4 discusses the statistical results obtained from the analysis. Section 5 outlines the managerial implications of the findings, offering recommendations for policymakers. Finally, Section 6 concludes the study, summarizing the key insights and suggesting directions for future research.

II. Literature Review and Development of Hypotheses

Pandemics like COVID-19 can have long-lasting negative effects on public health systems, posing significant challenges for both affluent and developing countries. These challenges can undermine decision-makers' abilities to respond effectively to the stressors brought about by such disasters. However, the efficacy of national responses varies significantly among countries, as demonstrated by Hjelmgaard (2020). This variation is largely due to differences in the implementation of critical measures such as testing, contact tracing, and quarantine protocols.

Using Data Envelopment Analysis (DEA), Dhaoui, (2019) explored the efficiency of healthcare systems in 18 countries in the Middle East and North Africa over several years. The study categorized these countries based on their health production efficiencies and health outcomes, revealing substantial differences among them. The DEA results indicated that while some countries were able to maintain high efficiency levels, others struggled, particularly in terms of technical efficiency and the impact of corruption and public spending on healthcare.

Le Page, (2020) emphasized that not all countries are equally prepared to handle a pandemic like COVID-19. The study highlighted that some nations, due to their advanced healthcare systems and better preparedness, are better placed to manage an outbreak than others. Nuzzo et al. (2020) further supported this view by using the Global Health Security Index to evaluate countries' readiness to cope with global health threats. The study found that while wealthier countries are generally well-equipped to manage such crises, many poorer countries lack the necessary resources, particularly in testing capacity, leading to less efficient responses.

Several studies have investigated the factors that influence national responses to crises like the COVID-19 pandemic. Hjelmgaard, (2020) attributed the variation in national responses to a country's ability to implement effective measures, such as easy and efficient access to testing and results. Similarly, Zeng et al. (2012) employed a Tobit model to identify factors affecting the efficiency of national HIV/AIDS programs in 68 low- and middle-income countries. Their findings indicated that a country's governance, financing mechanisms, and economic and demographic characteristics play a critical role in determining program efficiency.

Zanakis et al. (2011) analyzed the influence of social and economic factors on how well countries responded to the HIV/AIDS pandemic. Their study underscored the importance of socioeconomic conditions in shaping

national responses to health crises. In line with these findings, Nuzzo et al. (2020) attributed the disparities in COVID-19 responses to differences in testing capacity, with many poorer countries unable to respond as efficiently due to limited resources.

Legido-Quigley et al. (2020) focused on the economic resources available to countries, highlighting how these resources influenced the number of tests conducted and, consequently, the efficiency of their responses. Filchakova et al. (2020) confirmed the critical role of testing in pandemic management, attributing the differences in national responses to the varying levels of testing capacity across countries. Zhang and oh, (2024) extended this analysis by demonstrating that countries with superior healthcare coverage experienced fewer COVID-19-related deaths, further emphasizing the importance of robust healthcare systems in mitigating the impact of pandemics.

Giménez et al. (2024) compared the responses of various countries to the COVID-19 pandemic, showing that effectiveness is strongly influenced by socioeconomic and cultural factors. They found that countries with more cohesive social structures and better healthcare systems responded more effectively. Similarly, Min et al. (2022) examined cultural factors that critically influence the efficiency of COVID-19 control measures. Their study found that countries with less individualistic and higher uncertainty-avoiding cultures were more efficient in controlling COVID-19 outbreaks, as these cultural traits facilitated government-imposed control measures with minimal public resistance.

While the COVID-19 pandemic has spurred a vast amount of research, much of it is fragmented and lacks integration. The existing literature is extensive on specific factors like healthcare capacity, testing rates, and economic resources, but few studies have combined these elements to assess their collective impact on national pandemic responses. This fragmentation creates a gap in understanding how these factors interact to influence the efficiency of pandemic management. This study seeks to fill this gap by integrating the latest research findings and contributing to the ongoing debate on global health security and pandemic preparedness.

Hypothesis Development

This study aims to identify the key factors influencing the efficiency of national responses to the COVID-19 pandemic. Using an Undesirable Output DEA model, we evaluate the efficiency of healthcare systems across different nations and examine how robust healthcare infrastructures, testing rates, and various socioeconomic factors impact pandemic outcomes. This contributes to a broader understanding of effective response strategies. The following section outlines the development of our research hypotheses.

Effect of Testing Rate on Efficiency

A country's ability to provide testing during a pandemic is important when combatting a pandemic. Filchakova et al. (2020) stated that the best measure to contain the virus is through testing, as testing symptomatic patients can help prevent or slow its spread. The study underscores the importance of developing new, inexpensive detection methods, increasing the testing rate, and eventually resuming normal economic activities. Hjelmgaard, (2020) discussed the differences in the responses to countries' ability of implementing measures such as easy and efficient access to testing and results, rigorous contact tracing, consistent science-based messaging, quarantines and a genuine commitment to clamping down on socializing. With these measures, testing being one of them, countries can more efficiently halt the spread of the infection by knowing who has it and who they have been in contact with.

H1: If a country has a higher testing rate, it will be more efficient in combating pandemics.

Effect of Gross National Income on Efficiency

Higher Gross National Income (GNI) enables the purchase of more goods allowing for businesses to employ a larger number of people which in turn helps to stimulate the economy. Amid the COVID-19 crisis, research was performed to determine if a country with a higher GNI is more efficient in combatting an epidemic. Dhaoui, (2019) investigated the efficiency of health systems in 18 countries in the Middle East and North Africa using DEA. The study rejected the hypothesis that low-income countries cannot be a reference in terms of health efficiency. It also found that there is no correlation between the efficiency of the health system in these countries and their GNI per capita. Data also shows that health care systems in Hong Kong, Singapore and Japan have been able to adapt to the spread of the current COVID-19 (Legido-Quigley et al.,2020). However, it was stated that their resilience could be affected if the epidemic continues due to increasing number of people who will require

additional health care services. Organization for Economic Cooperation and Development (OECD) is an intergovernmental economic organization consisting of 37 developed countries with high-income economies. The 37 members are committed to democracy, market economy and policy collaboration between the members. In this paper, we hypothesized that countries with higher GNI, represented with OECD members will be more efficient in combating an COVID-19 pandemic.

H2: OECD Countries are more efficient in responding to the COVID-19 pandemic.

Effect of Universal Health Care System on Efficiency

McKibbin and Fernando, (2021) formulated seven scenarios which demonstrated that even a contained outbreak could significantly impact the global economy in the short run. These scenarios demonstrate the scale of costs that might be avoided by greater investment in public health care systems in all economies, but particularly in less developed economies where health care systems are less developed and population density is high. Many governments in less developed countries have been reluctant to invest sufficiently in their health care systems and let infectious diseases be originated from. Experts have warned that zoonotic diseases will continue to pose a threat to the lives of millions of people with potentially major disruption to an integrated world economy. Liberia, for example, worked to finalize a 10-year plan to build a stronger health system which focused on training 25,000 health care workers, hundreds of doctors and 8,000 nurses (Sy & Copley, 2015) in order to better combat pandemics.

H3: Countries with a universal health care system are more efficient in responding to the COVID-19 pandemic.

III. Model Development

For this study, we collected 151 countries' COVID-19 data from Johns Hopkins Coronavirus Resource Center, which tracks the reported cases of COVID-19 around the world (Johns Hopkins, n.d.). Countries with missing COVID-19 data were deleted, and as a result, 122 countries were used in this study. According to Cylus et al. (2016), health care efficiency measurement examines the extent to which the inputs to the health system, in the form of expenditure and other resources, are used to best effect to secure health system outputs. In this paper, we are focusing on the technical efficiency (TE) of countries' health care systems which will indicate the extent to which the system is minimizing the use of inputs in producing its chosen outputs. The input variables are population, number of hospitals, and number of hospital beds for each country. The output variables which are considered as an indicator of the heath care gains or losses produced from the inputs are number of COVID-19 reported cases, number of reported COVID-19 cases cured as well as reported deaths. The control variables are testing rate, advanced economic/democratic countries (OECD), and countries with universal health care system.

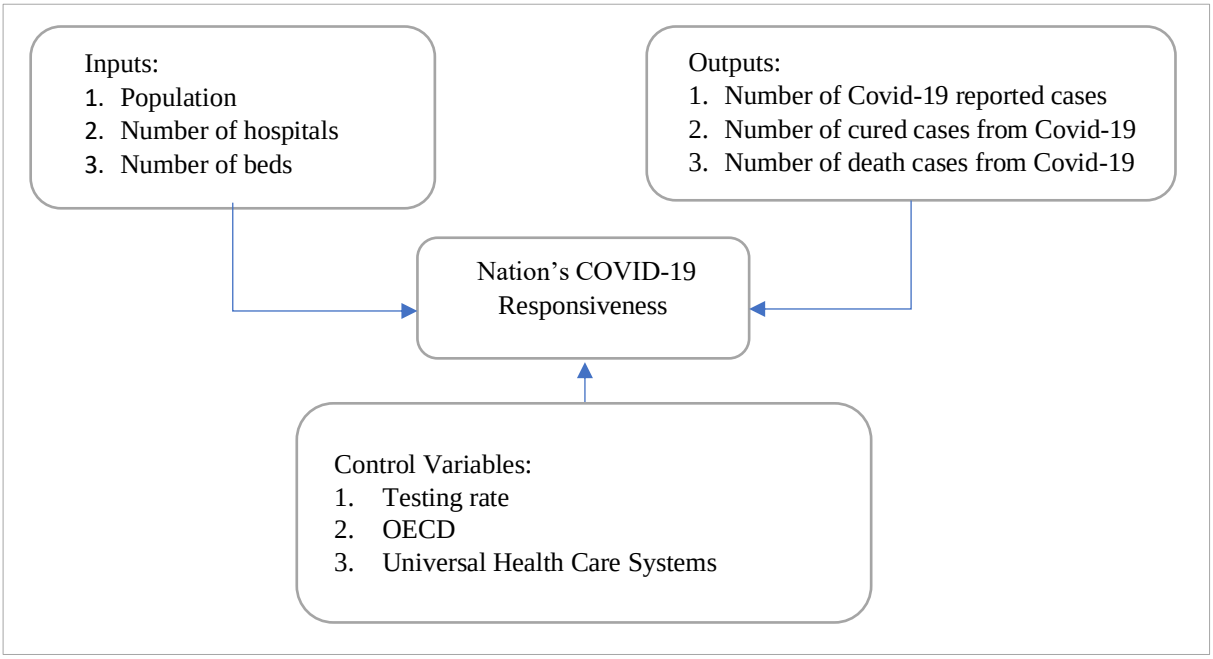

Figure 1: Model Development

Input Variable: Population

People's proximity might be the first factor to explain the transmissibility of pandemic viruses (Kadi & Khelfaoui, 2020). Several research studies have been questioned on the link between the density of the territories and the current epidemic and which have concluded that the relation is positive in most of the time (Bouda-Olga, 2020).

Input Variable: Number of Hospitals and Number of Beds

Number of hospitals and number of beds are considered critical factors in responding to COVID-19 (Srivastava, 2013) since lack of hospital beds and the medial devices raises the mortality rate of COVID-19. Data on the hospital bed was collected from the World Bank and last updated in 2020 (The World Bank, 2020). Number of hospitals per country data is obtained from the World Health Organization for the years 2010 to 2014 (The World Health Organization, n.d.).

Output Variable: Number of COVID-19 Reported Cases

Number of COVID-19 reported cases measures the magnitude of the 2019-2020 COVID-19 outbreak in terms of the daily cases. We used this metric to indicate the size of the problem that health care systems around the globe are facing as result of the outbreak. Data was collected from Johns Hopkins University as of April 7, 2020 (The Humanitarian Data Exchange, 2020).

Output Variable: Number of Reported COVID-19 Patient Cured and Deaths Cases

Number of patients cured as well as deaths have been directly linked to the efficiency of the countries' health care system. Number of patients cured, and deaths figures used in this study are based on COVID-19 data from Johns Hopkins University as of Abril 7, 2020 (The Humanitarian Data Exchange, 2020).

Control Variable: Testing Rate

Testing is the window onto the pandemic and how it is spreading. Because testing is crucial to understanding the spread of the pandemic and responding appropriately, we have focused our efforts on building a global dataset on COVID-19 testing. Without this data we cannot know which countries are doing well, and which are just underreporting cases and deaths. The number of tests as of April 6, 2020 were collected. Testing rate is defined as the proportion of the tests to the nation's population, i.e., the number of tests divided by a nation's population.

Control Variable: OECD

This variable indicates whether a country is listed under OECD which is an intergovernmental economic organization consisting of 37 developed countries with high-income economies and very high Human Development Index (HDI). The 37 members are committed to democracy, market economy and policy collaboration between the members. A country is coded as 1 if the country is not a member of OECD organization, and 2 if the county is a member of OECD organization.

Control Variable: Universal Health Care Systems

This variable classifies countries into two groups: countries with and without universal health care system. Universal coverage refers to a health care system where every individual has health coverage (Montgomery & Jegtvig, 2020). The data for the countries with universal health care system is published by New Your State, Department of Health (NY, Department of Health. n.d.).

Model Specification

Data envelopment analysis (DEA) was used to measure the comparative efficiencies of countries' health care systems in combating COVID-19 outbreak. In DEA, an organization measured for efficiency is called a decision-making unit (DMU). DEA uses linear programming to place weights on the inputs and outputs to compare the efficiency of DMUs.

There are undesired outputs. For instance, in our study, the number of COVID-19 death cases has a negative effect on efficiency. An undesirable output DEA model of which efficiency is measured by using the least number of

resources to create the highest number of good outputs while keeping the bad outputs low. Slacks-based measure of efficiency (Tone, 2001) was employed in this paper.

Saitech, (2016) described the undesirable output DEA model as follows. Suppose a hospital with *n* DMUs, each unit has three factors: inputs, desirable outputs and undesirable outputs as represented by three vectors correspondingly: $x \in R^m, y^g \in R^{s_1}, y^b \in R^{s_2}$ (Tone, 2001). Suppose the matrices X, Y^g, Y^b are defined as $X = [x_1, x_2, \dots, x_n] \in R^{m \times n}, Y^g = [y_1^g, y_2^g, \dots, y_n^g] \in R^{s_1 \times n}, Y^b = [y_1^b, y_2^b, \dots, y_n^b] \in R^{s_2 \times n}$ (Tone, 2001). Then the possibility set (P) is defined by $P = \{(x, y^g, y^b) | x \geq X\lambda, y^g \leq Y^g\lambda,\ y^b \leq Y^b\lambda, \lambda \geq 0\}$ where λ is the intensity vector (Tone, 2001). The vectors s^- and s^b correspond to excesses in inputs and bad outputs, respectively, while s^g expresses shortages in good outputs. Let an optimal solution be (p^*, s^{-*},s^{g*},s^{b*}). A given DMU (X_0,$Y^g{}_o$,$Y^b{}_o$) is efficient if and only if $p^* = 1$, and if the DMU is inefficient, $p < 1$ is satisfied. The DEA model dealing with undesirable outputs for evaluating DMU is as follows according to Tone (2001):

$$p^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_{i_0}^-}{x_{i_0}}}{1 + \frac{1}{s_1}\left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{r_0}^g} + \sum_{r=1}^{s_1} \frac{s_r^b}{y_{r_0}^b}\right)}$$

subject to

$$x_0 = X\lambda + s^-$$

$$y_0^g = Y^g\lambda - s^g$$

$$y_0^b = Y^b\lambda + s^b$$

$$L \leq e\lambda \leq U$$

$$s^-, s^g, s^b, \lambda \geq 0.$$

This study used DEA-Solver-Pro (Professional Version 13.0) software to measure the relative efficiency which was estimated the level of each nation's responsiveness to COVID-19 pandemic. Every DEA model assumes returns to scale (RTS) characteristics that is represented by the ranges of the sum of the intensity vector λ, i.e., $L \leq \lambda_1 + \lambda_2 + \cdots + \lambda_n \leq U$. The constant RTS corresponds to ($L = 0$, $U = \infty$), and the variable RTS to ($L = 1$, $U = 1$), respectively. DEA-Solver-Pro offered six different undesirable output models.

Among the models, this study chose Bad Output-C and Bad Output-V models. The defaults of the Bad Output model in DEA-Solver-Pro set the ratio of total weights to good outputs and bad outs at 1:1. Bad Output models were all output-oriented. We denoted UO-BO-C for the Undesirable Outputs Bad Output-Constant DEA model while UO-BO-V indicated the Undesirable Outputs Bad Output-Variable DEA model in reporting the DEA results. The UO-BO-C model used constant returns-to-scale (CRS) for computing efficiency scores. This model is similar to the CCR-O model and computed the technical efficiency (TE). The UO-BO-V model used variable returns-to-scale (VRS). This model is similar to the BCC-O model and computed the pure technical efficiency (PTE). The scaled efficiency (SE) could be computed by diving TE into PTE. PTE would indicate an internal source of inefficiency while SE would present an external source of inefficiency.

IV. Results

This section presents the results and findings of the study, elaborating on how each table and figure supports the proposed hypotheses. Table 1 shows the descriptive statistics of the input and output variables used for the analysis. These statistics highlight the variability in the population size, number of hospitals, number of beds, and COVID-19-related cases across the 122 countries in the sample. The wide range in the variables underscores the diversity in healthcare infrastructure and the impact of the pandemic across different nations, setting the stage for an analysis of efficiency using the DEA model. In addition, Table 2 illustrates the correlations of input and output variables. The correlation analysis in Table 2 highlights the complex interplay between healthcare infrastructure, population size, and pandemic outcomes. It underscores the importance of not only having robust healthcare systems but also implementing effective strategies and policies to manage the spread and impact of COVID-19.

Table 1. Input and Output Variables

Variables		Minimum	Maximum	Mean	Std. Dev.
	Population	77,265	1,439,323,776	57,656,766.40	183,973,351.35
Input	# of Hospitals	1	23,640	1,083.95	3,207.78
	# of Beds	210	4,405,770	148,230.73	463,981.56
Output	# of Cases	25	1,831,821	51,726.75	181,453.93
	# of Cured Cases	0	463,868	22,120.02	57,143.48
	# of Death Cases	1	106,180	3,104.23	11,477.81

Source: Author(s) own work

Table 2. Correlation Results of Variable

..	(1)	(2)	(3)	(4)	(5)	(6)
(1) Population	1.000					
(2) # of Hospitals	0.706	1.000				
(3) # of Beds	0.793	0.709	1.000			
(4) # of Cases	0.251	0.297	0.204	1.000		
(5) # of Cured Cases	0.330	0.392	0.255	0.914	1.000	
(6) # of Death Cases	0.192	0.240	0.160	0.932	0.385	1.000

Source: Author(s) own work: **Note** (s): (# of hospital =2, # of beds =3, # of cases = 4, # of cured cases = 5, # of death cases = 6)

H1: If a country has a higher testing rate, it will be more efficient in combating pandemics.

To test this hypothesis, we collected data on COVID-19 testing and calculated the testing rate as the proportion of tests to the nation's population. As shown in Table 3, the Spearman's correlation test shows a positive relationship between DEA efficiency scores (UO-BO-C and UO-BO-V) and the testing rate. Specifically, countries with higher testing rates demonstrated significantly higher efficiency scores, indicating that the number of testings is crucial for effective pandemic management. These results strongly support Hypothesis 1, as they confirm that increased testing capacity allows countries to detect and isolate infected individuals, reducing the spread of the virus and enhancing overall efficiency in managing the pandemic.

Table 3. Spearman's Correlations between Nation's Responsiveness and Tests

	(1)	(2)	(3)
(1) UO-BO-C	1		
(2) UO-BO-V	.720***	1	
(3) Testing Rate	.697***	.620***	1

***p < 0.001, N = 58

Source: Author's own work

H2: OECD Countries are more efficient in responding to the COVID-19 pandemic.

This study uses the Mann-Whitney test to compare the efficiency of OECD and non-OECD countries in responding to COVID-19. The results presented in Table 4. The results show a statistically significant difference between the two groups, with OECD countries showing higher efficiency scores on both DEA models (UO-BO-C and UO-BO-V), supporting Hypothesis 2. It implies that the advanced economies and well-established healthcare systems of OECD countries enable them to respond more effectively to the pandemic. The results are

in line with the notion that higher GNI and more economic resource allocation, which are common among OECD members, contribute to more efficient pandemic management.

Table 4. Mann-Whiney Test Results by OECD

DEA Model	OECD	N	Mean	Std. Dev.	Mean Rank	M-W U	Z	*p*-value
	Non-OECD	88	.0776	.2105	54.65			
UO-BO-C	OECD	34	.1263	.1929	79.24	893.00	-3.443	0.001
	Total	122	.0912	.2062				
	Non-OECD	88	.2226	.3633	57.13			
UO-BO-V	OECD	34	.4020	.4406	72.81	1111.50	-2.206	0.027
	Total	122	.2726	.3929				

Source: Author's own work

H3: Countries with a universal health care system are more efficient in responding to the COVID-19 pandemic.

Table 5 compares the efficiency of countries with and without a universal healthcare system (UHC) using the Mann-Whitney test. The results show that countries with UHC have significantly higher efficiency scores in both DEA models (UO-BO-C and UO-BO-V), supporting Hypothesis 3. This finding underscores the importance of universal healthcare coverage in ensuring an effective response to pandemics. UHC systems provide broader access to healthcare services, enabling quicker identification, treatment, and isolation of COVID-19 cases, which contributes to higher national efficiency in managing the pandemic.

Table 5. Mann-Whitney Test Results by Universal Health Care Systems

DEA Model	UHC	N	Mean	Std. Dev.	Mean Rank	M-W U	Z	*p*-value
	Non-UHC	91	.0527	.1530	53.18			
UO-BO-C	UHC	31	.2041	.2891	85.94	653.00	-4.455	0.000
	Total	122	.0912	.2062				
	Non-UHC	91	.2103	.3593	55.41			
UO-BO-V	UHC	31	.4555	.4346	79.37	856.50	-3.274	0.001
	Total	122	.2726	.3929				

Source: Author's own work

V. Discussion

This study found a strong correlation between a nation's efficiency score and the number of COVID-19 tests performed; as the number of tests increases, efficiency scores also increase. The Spearman's correlation results show statistical significance across all three DEA models, with a p-value less than 1%. This finding highlights the crucial role of widespread testing in managing pandemics effectively, aligning with (Shear et al., 2020), who noted that the failure to implement aggressive screening early on contributed significantly to the spread of COVID-19 in the U.S. This supports the notion that proactive testing is essential for national efficiency in pandemic response. However, this finding contradicts Molla and Scott (2020), who reported no relationship between the number of COVID-19 tests performed and a country's responsiveness to the pandemic. The divergence between these findings underscores the complexity of pandemic management and suggests that other contextual factors, such as the timing and logistics of testing, may play a critical role.

The study also reveals that developed countries are generally more efficient in responding to COVID-19 than less developed countries. This result is consistent with (Kleinfeld, 2020), who observed that regime type alone does not determine a country's efficiency in pandemic response. Kleinfeld's work showed that while some autocracies, like Singapore, performed well, others, like Iran, struggled significantly. Similarly, some democracies, such as Italy and the United States, encountered severe challenges, whereas others, like South Korea and Taiwan, managed

the pandemic effectively. Our findings extend this understanding by emphasizing the role of economic development and healthcare infrastructure in enhancing national efficiency. This insight is particularly valuable for policymakers in less developed countries, as it underscores the need for strategic investments in healthcare and pandemic preparedness.

Furthermore, the study found a strong relationship between having a universal healthcare system and national efficiency in overcoming the COVID-19 pandemic. The results are statistically significant across all three DEA models, with less than a 1% significance level. Countries with universal healthcare systems demonstrated the highest efficiency scores, confirming the findings of (McKibbin & Fernando, 2021), who argued that greater investment in healthcare systems is vital for managing global health crises. This study extends the current knowledge by providing empirical evidence that universal healthcare systems not only improve access to healthcare but also enhance a country's overall efficiency in responding to pandemics. This has significant implications for policymakers, particularly in countries without universal healthcare, suggesting that expanding healthcare access could be a key strategy in bolstering national resilience against future pandemics.

In summary, these findings support the growing body of research advocating for increased investment in public health systems to manage pandemics more effectively. The data analysis also indicates that an increase in testing capacity is directly linked to higher national efficiency scores, reinforcing the importance of widespread testing as a critical component of pandemic response. Additionally, the presence of universal healthcare systems within a country was shown to significantly improve its efficiency in handling the COVID-19 pandemic. For regulators and policymakers, these insights provide a compelling case for prioritizing healthcare system improvements and pandemic preparedness to mitigate the impact of future global health crises.

VI. Conclusion

This research provides valuable insights into the factors influencing a country's efficiency in responding to a pandemic, with a particular focus on COVID-19. The study establishes a robust and statistically significant correlation between the number of COVID-19 tests conducted and a nation's efficiency score, highlighting the critical role of testing in pandemic management. Additionally, the research identifies a trend wherein developed countries generally demonstrate higher efficiency in handling the pandemic compared to their less developed counterparts. The strong correlation between the presence of a universal healthcare system and national efficiency in pandemic response underscores the imperative of investing in robust public health systems.

Implications

The implications of these findings are significant for both current research and policy debates. In the context of global health security, this study reinforces the importance of comprehensive testing strategies and well-funded healthcare systems as foundational elements for effective pandemic response. These findings align with ongoing discussions in public health literature, which advocate for stronger healthcare infrastructure and preparedness measures, particularly in the wake of COVID-19. For policymakers, the research suggests that strategic investments in healthcare infrastructure, including the expansion of universal healthcare, can substantially enhance a country's resilience against future pandemics. This recommendation is particularly relevant as governments worldwide reassess their public health strategies in light of the pandemic's lessons.

Limitations and Future Research

In addressing the limitations of this study, it is important to acknowledge that the data used were limited to the initial stages of the COVID-19 pandemic. As such, the findings should be interpreted with caution, as the situation has continued to evolve with new data emerging over time. Additionally, the study's reliance on DEA models, while suitable for the analysis conducted, may not capture all the complexities of pandemic response efficiency. Future research could benefit from incorporating additional variables, such as social distancing measures, vaccination rates, and economic support programs, to provide a more comprehensive understanding of national efficiency in pandemic management. Moreover, alternative econometric models could be employed to validate and extend the findings presented here.

Future research should also explore comparative analyses between the COVID-19 pandemic and other global health crises, such as SARS, MERS, and Ebola, to identify common factors that influence national efficiency in pandemic response. By grounding these future studies in the strengths and limitations identified in this research, scholars can contribute to a more nuanced understanding of how different countries can better prepare for and respond to global health emergencies.

Competing interest statement

This research was conducted in the absence of any commercial or financial relationships among authors and they do not have any potential conflict of interest.

Author (s) contribution Statement

C. Christopher Lee and Mohamed Ahmed contributed to the conception and design of the study. C. Christopher Lee, Mohamed Ahmed, and Heechang Shin wrote the introduction section. C. Christopher Lee, Mohamed Ahmed, Heechang Shin, and Benjamin S. Lee wrote the literature review and hypothesis development sections. C. Christopher Lee, Mohamed Ahmed, and Benjamin S. Lee wrote the methodology section. C. Christopher Lee, Mohamed Ahmed, and Soomin Park organized the database, performed the statistical analysis and interpreted the results. Benjamin S. Lee, Heechang Shin and Soomin Park proofread the paper. Heechang Shin and Soomin Park edited the paper in compliance with the AJBMR. All authors contributed to manuscript revision, read, and approved the submitted version.

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