Using Data Envelopment Analysis to Measure the Efficiencies of Saskatchewan's Health Regions during the COVID-19 Pandemic

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Abstract

We develop empirical bootstrap data envelopment analysis models to evaluate the relative efficiencies of Saskatchewan's various health regions in handling the health emergency situation created by the coronavirus (COVID-19) pandemic. Each region's relative success in managing the influx of COVID-19 cases was assessed based on input and output variables associated with efficiency. Our findings show that Saskatchewan has done a good job of handling the COVID-19 pandemic from a managerial point of view, but not in terms of the effective utilization of resources. We further use the data envelopment analysis models to identify the most efficient health regions, which in turn serve as benchmarks that the other regions can follow in improving their respective efficiencies. The findings of this study can assist decision makers in developing policies that will enable efficient management of the pandemic, and mitigate health inequities for populations in different health regions.

Keywords
Bootstrap data envelopment analysis, COVID-19 pandemic, Overall technical efficiency, Pure technical efficiency, Scale efficiency.

1. Introduction
The novel coronavirus (COVID-19) has spread quickly all over the world, creating a global health emergency challenge unlike anything seen in recent times. As of March 26, 2021, more than 126 million cases of COVID-19 and more than 2.7 million deaths had been recorded worldwide (John Hopkins University 2021). The high influx of COVID-19-related cases has highlighted individual health regions' lack of necessary healthcare personnel, equipment, and medicine, and has pushed health systems to the point of collapse (Nepomuceno et al. 2020). One potentially effective approach to dealing with this critical situation would be to develop an in-depth understanding of the operations of the health care system, and to find ways of improving the relative efficiency of resource allocation across its respective health regions (Yang 2017). Data Envelopment Analysis (DEA) is a non-parametric approach that has been commonly used to estimate the relative efficiency of health care systems (Oh et al. 2016), as it is capable of handling disproportionate input and output combinations without assuming a mathematical frontier function (Arnold et al. 1996). The bootstrap DEA methodology further takes into account any uncertainty by constructing confidence intervals and finding robust efficiency estimators (Simar & Wilson 1998). A number of previous studies have used the DEA approach to measure the relative efficiency of hospitals and long-term care facilities in different parts of the world (Knox et al. 2007, Zare 2019, Mitropoulos 2021). The DEA model analyzes three typical types of relative

efficiencies: (i) the overall technical efficiency (OTE), which measures the effective utilization of input resources, (ii) the pure technical efficiency (PTE), which measures the managerial skills in handling the pandemic, and (iii) the scale efficiency (SE), which measures whether the scale of operations of the health units is optimal or not. Further the DEA meta-frontier analysis benchmarks and compares each region's relative efficiency with the combined efficiency frontier. A health region's rate of increase of confirmed COVID-19 cases and related deaths is a main indicator of its preparedness to deal with the pandemic. These indicators, along with the recovery rate, serve as a useful measure for assessing how efficiently a health region has controlled and managed the disease.

There have been attempts to model COVID-19 transmission in different parts of the world, including Canada (Chimmula & Zhang 2020, Tuite et al. 2020), but we are unaware of any prior work that has studied the relative efficiency with which Canada's health regions have dealt with the pandemic. The purpose of this study is to close this gap in literature by creating DEA models to measure and compare health regions' relative efficiencies in handling the COVID-19 pandemic. The specific objectives of this study are to create Bootstrap DEA models to measure and compare the three relative efficiencies (PTE, OTE and SE) for the health regions of Saskatchewan Health Authority (SHA). In addition, we run the meta-frontier analysis for benchmarking, and for comparing the relative efficiency of each health region of Saskatchewan with the combined efficiency of the entire province in handling the pandemic. The DEA is a non-parametric approach for efficiency evaluation that can handle disproportionate inputs and outputs combinations without assuming a mathematical function. The bootstrap DEA methodology further takes into account any un-certainty by constructing confidence intervals and finding robust efficiency estimators (Simar & Wilson 1998). The inputs included in the DEA model include: (i) new cases, (ii) total cases, and (iii) active cases; and the outputs include: (i) Inpatient hospitalizations, (ii) ICU hospitalizations, (iii) recovered cases, and (iv) deaths. The data for the inputs and outputs were obtained from the from Saskatchewan key COVID-19 indicators available on the health-wellness website (Saskatchewan 2020).

This study provides new insights for identifying inefficiencies within health regions, and advocating for equitable access to health care for those infected with COVID in the region. Although, the proposed model was applied to evaluate the performance of Saskatchewan's health regions in handling the COVID-19 pandemic, the model and solution methodology can be applied for any province or state. The Saskatchewan Health Authority (SHA) consists of 13 health regions that are responsible for providing high-quality and timely healthcare services to people living in the province's urban, rural, and remote areas. Each region has limited health resources, with resource scarcity being more pronounced in the province's rural and remote regions. Thus, the developed DEA models were employed to evaluate the relative efficiencies of the SHA's health regions in dealing with the COVID-19 pandemic (as of Jan. 7, 2021), as such data will be critical in addressing these issues. In order to understand the relative efficiencies of Saskatchewan's health regions, we have grouped the 13 health regions into six larger regions based on geographic location (Table 1).

Table 1: Combined health regions of Saskatchewan.

Region	Health Regions
Far North	1. Far North West
	2. Far North Central
	3. Far North East
North	4. North West
	5. North Central
	6. North East
Central excluding Saskatoon	7. Central West
	8. Central East
Saskatoon	9. Saskatoon
South excluding Regina	10. South West
	11. South Central
	12. South East
Regina	13. Regina

The rest of the paper is organized as follows: Section 2 provides a review of the literature related to the use of DEA models in the healthcare system and in modeling the COVID-19 pandemic; Section 3 details the development of the models used for DEA and meta-frontier analysis; Section 4 presents the data, variables, and some descriptive statistics.

The empirical findings are discussed in Section 5, while Section 6 outlines the managerial insights produced by this research, and Section 7 provides some concluding remarks.

2. Literature Review

The need to evaluate the efficiency of healthcare systems has become particularly salient due to the sudden and immense pressure that has been placed on these systems' limited resources by the COVID-19 pandemic (Nepomuceno et al. 2020). To date, efficiency-based models have largely used simulation and forecasting techniques to generate new insights into how to optimize the use of healthcare facilities, personnel, and equipment (Ordu et al. 2020). However, due to the limitations of these simulation and forecasting techniques, the non-parametric DEA approach has been commonly used to estimate the relative efficiencies of healthcare systems, as it is able to identify inefficient units and benchmark efficient ones (Oh et al. 2016). In this section, we review the literature related to the use of DEA in healthcare systems and in modeling the COVID-19 pandemic.

2.1 DEA Models for Healthcare Systems

While several methods have been used to evaluate the efficiency of healthcare systems (Büyüközkan et al. 2016), the DEA method has become the preferred approach due to its ability to handle multiple outputs and inputs (Kohl et al. 2019). A recent literature review of DEA applications in healthcare can be found in Cantor and Poh (2018). In general, the following inputs are used to evaluate hospital efficiency: (i) number of beds for hospitalizations; (ii) medical equipment; (iii) drugs and pharmaceuticals; (iv) health care professionals (physicians, nurses, unlicensed assistants, and other staff); and (v) hospital infrastructure (Nepomuceno et al. 2020). Conversely, the following outputs are most commonly used to evaluate the efficiency of healthcare systems: (i) number of in-patient days; (ii) number of patients discharged; (iii) number of emergency visits; (iv) number of patients with a specific disease that were handled; and (v) number of medical staff trained (Linna 1998). Notably, the DEA method has been used to assess the relative efficiencies of similar healthcare units. For instance, Kazley and Ozcan (2009) employed DEA to analyze the relative gain in efficiency from using electronic records in hospitals. Although, the DEA is a very powerful technique that can handle several inputs and outputs, it is limited by its deterministic nature and its inability to handle uncertainty associated with inputs or outputs.

Several researchers have combined the classical DEA technique with other techniques, such as bootstrapping and fuzzy set theory, in an attempt to accommodate the inherent uncertainty associated with the deterministic DEA models. Otay et al. (2017) conducted a comprehensive literature review of all techniques that have been employed to measure healthcare system efficiency, and divided them into three groups: (i) classical DEA using bootstrapping or fuzzy techniques (Ebrahimnejad 2012); (ii) classical DEA techniques integrated with simulation models (Mitropoulos et al., 2013); and (iii) new and modified DEA models for healthcare systems (Leleu et al. 2014). In addition, there are many studies that use other comprehensive and multi-dimensional performance evaluation tools in an attempt to improve the quality of service provided to patients and communities (Kloot & Martin 2000, Yang & Tung 2006). However, all these studies focus on improving the performance of specific hospitals using different evaluation criteria (Arah et al. 2006). The advantage of using DEA to compare the relative efficiencies of multiple health regions is that it evaluates each region's efficiency by comparing it to the efficiencies of the other regions, while allowing each region in the dataset to have its own production (service) function. Given these advantages, we use DEA models to evaluate and compare the relative efficiencies of Saskatchewan's healthcare regions.

2.2 Modeling the COVID-19 Pandemic

The published literature on the COVID-19 pandemic has thus far primarily focused on modeling the progression of the disease in communities (Tuite et al. 2020). This represents a key gap in the literature, as hospital emergency departments have been among the hardest hit by the pandemic due to having to treat the growing influx of COVID-19-affected patients. Gul and Guneri (2015) conducted a comprehensive literature review of the operation of hospital emergency departments, and concluded that simulation techniques may be an effective tool for improving operational efficiency, especially in times of a disaster. During the COVID-19 pandemic, healthcare systems have not only become overburdened from having to treat COVID-19-affected patients, but also from having to continue to provide treatment and surgeries to non-COVID-19 patients. As a result of these competing demands, the ability of healthcare systems to provide efficient, high-quality treatment has been severely compromised (Shirouyehzad et al. 2020). Research focusing specifically on the Canadian context has concentrated on using epidemiological models to study the transmission dynamics of COVID-19 (Tuite et al. 2020), with the sole purpose of minimizing societal disruption due to morbidity and mortality. In particular, these studies have focused on finding non-pharmaceutical interventions able to minimize the number of cases requiring in-patient medical care in hospitals and intensive care unit admissions (Tuite et al. 2020). However, there have been no studies that have focused on evaluating the healthcare system's current level of efficiency, and finding ways to enhance efficiency by diverting input resources to regions where they are lacking. It is prudent for decision makers to continuously assess and work to understand the relative efficiency of healthcare systems, and to ensure that healthcare policies are being effectively implemented.

3. Methods

3.1 The Data Envelopment Analysis Model

The DEA model is a non-parametric linear programming method that measures the relative efficiencies of several Decision Making Units (DMUs) (Lovell 1993). It compares the inputs and outputs of selected health regions by establishing an efficiency frontier, and then evaluating the efficiency of all DMUs in relation to that frontier (Charnes et al. 1978). It analyzes three types of relative efficiencies: (i) overall technical efficiency (OTE), which measures the effective utilization of input resources; (ii) pure technical efficiency (PTE), which measures managerial skills; and (iii) scale efficiency (SE), which measures whether the health region's scale of operations is optimal.

The first DEA model, which was developed by Charnes, Cooper, and Rhodes (1978), is known as the CCR model, and assumes constant returns to scale. The CCR model estimates the OTE and assesses both the management and scale of operations. The dual model of the CCR-oriented input is represented as follows:

$$\min\ \theta_0 = z_0 - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{t} s_r^+\right) \quad (1)$$
$$x_{ij_0} z_0 - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0,\ i = 1 \dots m \quad (2)$$
$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rj_0},\ r = 1 \dots t \quad (3)$$
$$\lambda_j, s_i^-, s_r^+ \geq 0,\ j = 1, \dots, n,\ i = 1, \dots, m,\ r = 1, \dots, t \quad (4)$$

Where θ_0 is the efficiency ratio of the benchmark, DMU_0, n is the number of DMUs, t is the number of outputs, m is the number of inputs, x_{ij} is the value of the input, i, for DMU_j, and y_{rj} is the value of the output, r, for DMU_j. The parameter, λ_j represent the benchmark DMUs and define an envelope for the evaluated DMU_0. The parameter, z_0 indicates the proportion of inputs required by an inefficient DMU to produce outputs equivalent to the benchmark DMUs. The parameters, s_i^- and s_r^+ correspond to the slacks associated with the input, i, and output, r, respectively.

The second model, developed by Banker, Charnes, and Cooper (1984) and known as the BCC model, assumes variable returns to scale. The BCC model estimates the PTE and only assesses the management of operations. The dual-input BCC model is obtained by adding a convexity constraint to the CCR model in Equations (1-4):

$$\sum_{j=1}^{n} \lambda_j = 1 \quad (5)$$

Since the BCC model computes efficiency based on management effectiveness, the results obtained via this model can be further decomposed into efficiency related to management effectiveness and scale of operations. The scale efficiency, θ_0^{SE}, in Equation (6) evaluates whether the health region has the amount of resources it requires to operate, and the optimum scale of operations.

$$\theta_0^{SE} = \frac{\theta_0^{CCR}}{\theta_0^{BCC}} \quad (6)$$

Simar and Wilson (1998) improved the DEA model by applying bootstrapping methodology to frontier models, which enabled the construction of confidence intervals and the acquisition of robust efficiency scores. In our study, we ran 2000 iterations of this procedure to ensure the convergence of the confidence intervals.

3.2 Group Frontier and Meta-Frontier

All of Saskatchewan's health regions have a different production function due to inter regional heterogeneity with respect to resources. Therefore, measuring the relative technical efficiencies of an individual health region cannot provide a complete picture of healthcare efficiency on a provincial scale (Bhandari & Valiyattoor 2016). Rather, a group frontier (also called the local frontier) can be created for each health region, and a meta-frontier (or grand-frontier) can also be created by amalgamating all of Saskatchewan's health regions into one group. A particular health region can thus be evaluated against these two frontiers.

The disparity of resources between health regions creates different healthcare service possibilities in handling the pandemic. We assume that there are n health care units in the province, such that $j = 1,2, ..., n$. Furthermore, these health care units are classified into h distinct groups (health regions), where the g^{th} group contains n_g health care units.

The within-group technical efficiency (TE_g^k) of healthcare unit k (belonging to group g) is obtained using the CCR model specified in Equations (8-11):

$$\min TE_g^k = \theta_g^k; \quad (8)$$

$$\text{Subject to: } \sum_{j \in J_g} \lambda_{gj} x_g^j \le \theta_g^k x_g^k; \quad g=1,\dots,h;\ j=1,\dots,n;\ k=1,\dots,n_g \quad (9)$$

$$\sum_{j \in J_g} \lambda_{gj} y_g^j \ge y_g^k; \quad g=1,\dots,h;\ j=1,\dots,n;\ k=1,\dots,n_g \quad (10)$$

$$\lambda_{gj} \ge 0 \quad ; \quad g=1,\dots,h;\ j=1,\dots,n \quad (11)$$

The meta-frontier is the outer envelope of all of the group frontiers, and comprises the boundary points of the input-output vectors of all healthcare units in the sample. The grand technical efficiency (TE_G) of healthcare unit k of the g^{th} group is obtained by solving the linear program problem (Eqs. 12-15).

$$\min TE_G^k = \theta_G^k; \quad (12)$$

$$\text{Subject to } \sum_{g=1}^{h} \sum_{j \in J_g} \lambda_{gj} x_g^j \le \theta_G^k x_g^k; \ g=1,\dots,h;\ j=1,\dots,n;\ k=1,\dots,n_g \quad (13)$$

$$\sum_{g=1}^{h} \sum_{j \in J_g} \lambda_{gj} y_g^j \ge y_g^k; \quad g=1,\dots,h;\ j=1,\dots,n;\ k=1,\dots,n_g \quad (14)$$

$$\lambda_{gj} \ge 0\,; \quad g=(1,\dots,h);\ j=1,\dots,n \quad (15)$$

4. Data Collection

The data for this study were collected from the Saskatchewan Government dashboard, health and wellness, total COVID cases website (Saskatchewan 2021). The Government dashboard provides up-to-date information about new, confirmed, active and recovered cases by region, in addition to inpatient and intensive care unit (ICU) hospitalizations by region. In this paper, data from August 04, 2020 (when the website reported the COVID cases for all the regions, and the number of cases had begun to increase rapidly) to January 07, 2021 (the day on which the analysis was conducted) was downloaded for the six analyzed regions.

The input variables included:

- New cases on day d in region j (j=1,…,6)
- Total cases to date (or cumulative number of cases) in region j (j =1,…,6)
- Active cases on day d in region j (j=1,…,6)

The outputs of the DEA model included:

- Number of current inpatient hospitalizations on day d in region j (j=1,…,6)
- COVID-19-related ICU hospitalizations on day d in region j (j=1,…,6)
- Total recovered cases to date in region j (j=1,…,6)
- Deaths to date in region j (j=1,…,6)

The descriptive data for the six health regions are shown in Table 2. The data show that a majority of Saskatchewan's COVID cases had been reported in three regions (Saskatoon, Regina, and North). Saskatchewan's health regions vary in area and in population. According to the 2016 census, Saskatchewan has 51.6% of the population living in the Saskatoon and Regina health regions. In contrast, the Far North region has the smallest population at 3.4% of Saskatchewan's total population. The number of new daily COVID-19 cases varies across the six health regions due to differences in their populations. However, each region has been handling COVID-19 patients based on their available resources.

Table 2: Descriptive input and output variables for six health regions in Saskatchewan.

Region	Average Cases per week	Total Cases	Active Cases	Inpatient Hospitalizations	ICU Hospitalizations	Recovered Cases	Deaths
Saskatoon	211	4631	465 (10.0)	2647 (57.2)	760 (16.4)	4134 (89.3)	32 (0.7)
Regina	150	3300	475 (14.4)	1334 (40.4)	449 (13.6)	2770 (83.9)	55 (1.7)
North	194	4271	265 (6.2)	1521 (35.6)	319 (7.5)	3268 (76.5)	46 (1.1)
Far North	93	2037	375 (18.4)	86 (4.2)	0 (0.0)	1500 (73.6)	13 (0.6)
Central	46	1018	51 (5.0)	176 (17.3)	33 (3.2)	846 (83.1)	6 (0.6)
South	79	1741	108 (6.2)	734 (42.2)	66 (3.8)	1476 (84.8)	25 (1.4)

The number in brackets are the percentage of total cases

Figure 1 shows the new and active cases in the six health regions over the study period. As can be seen, the number of new and active cases peaked in November 2020, with the largest number of new and active cases being reported in the Saskatoon and Regina health regions. Furthermore, the largest proportion of total active cases were reported in the Far North region (18.4%), followed by the Regina (14.4%) and Saskatoon (10%) health regions (Table 2).

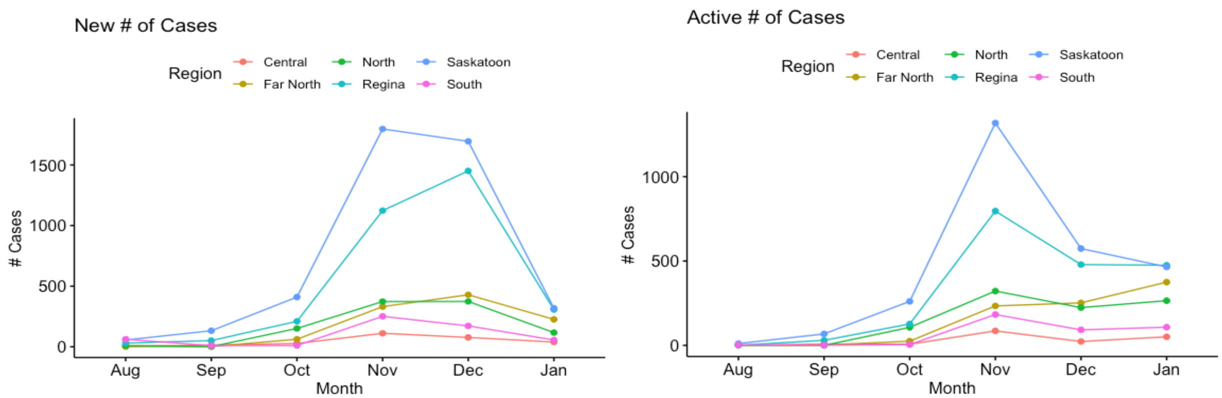


Figure 1: New and active cases in six health regions in Saskatchewan over the study period.

Figure 2 shows the total and recovered cases in the six health regions over the study period. As can be seen, the total number of cases suddenly increased in October 2020, with the Saskatoon, Regina, and Northern health regions reporting the largest numbers of cases. The high percentage of recovered cases indicates that the COVID-19 pandemic has been well managed in the different regions of the province. ICU hospitalizations have remained above 10% in the Saskatoon and Regina health regions, whereas the number of deaths in each region has been below 2% of the total reported cases in each.

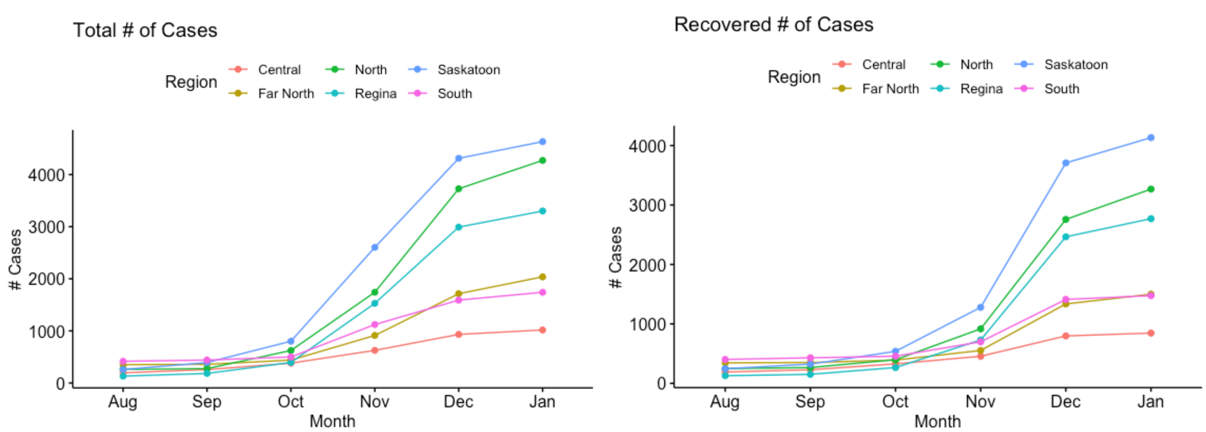


Figure 2: Total and recovered cases in six health regions in Saskatchewan over the study period.

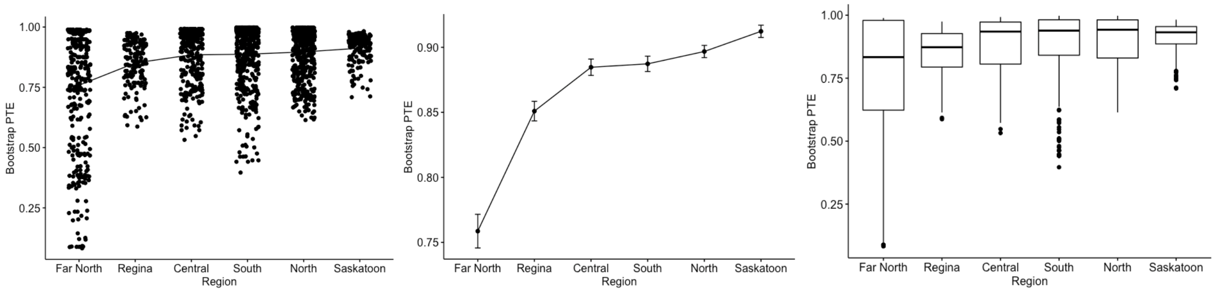
5. Results and Discussion

The DEA model analyzes three types of relative efficiencies: (i) pure technical efficiency (PTE); (ii) overall technical efficiency (OTE); and (iii) scale efficiency (SE). Table 3 shows the descriptive statistics (mean, median, and standard deviation) relating to these relative efficiencies for the six health regions of the province. The results show that the PTE is higher than the OTE for all six health regions. This indicates that the COVID-19 pandemic has been handled well from a managerial perspective, but not with respect to the effective utilization of resources available within the health regions. The SE, which measures the health units' relative scale of operations, was high for all six health regions, which indicates that each region's scale of operation is optimal in terms of managing COVID-19 patients.

Table 3: Descriptive statistical measures of efficiencies obtained via bootstrap DEA models.

Region		Pure Technical Efficiency (PTE)		Overall Technical Efficiency (OTE)		Scale Efficiency
		Regular	Bootstrap	Regular	Bootstrap	
Far North	Mean	0.77	0.76	0.74	0.74	0.96
	Median	0.85	0.83	0.79	0.79	0.98
	Std Dev	0.25	0.25	0.25	0.25	0.10
North	Mean	0.91	0.90	0.84	0.83	0.92
	Median	0.97	0.94	0.86	0.85	0.99
	Std Dev	0.10	0.10	0.14	0.14	0.11
Saskatoon	Mean	0.94	0.91	0.87	0.84	0.93
	Median	0.96	0.93	0.91	0.89	0.95
	Std Dev	0.07	0.06	0.11	0.10	0.08
Central	Mean	0.90	0.88	0.88	0.87	0.98
	Median	0.95	0.93	0.93	0.92	1.00
	Std Dev	0.12	0.11	0.12	0.12	0.04
Regina	Mean	0.88	0.85	0.85	0.82	0.97
	Median	0.90	0.87	0.88	0.85	0.99
	Std Dev	0.10	0.09	0.12	0.11	0.06
South	Mean	0.90	0.89	0.89	0.88	0.99
	Median	0.98	0.94	0.95	0.93	1.00
	Std Dev	0.13	0.13	0.13	0.13	0.04
All Regions	Mean	0.88	0.86	0.84	0.83	0.96
	Median	0.95	0.92	0.90	0.88	0.99
	Std Dev	0.16	0.15	0.17	0.16	0.08

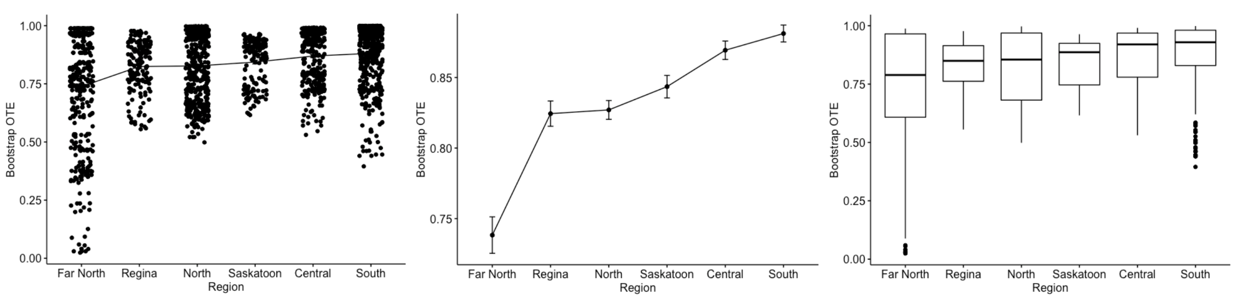
Figure 3 shows the scatter plot with means (a), means and standard errors (b), and box plots showing the medians, upper and lower quartiles, and whiskers indicating variability outside the upper and lower quartiles for the PTEs of all six regions (c). As the results show, the Far North region's PTE is characterized by very high day-to-day variability in the management of COVID-19 patients. Significantly, all six regions have high day-to-day variability in PTE, which indicates that efficiency with which these health units are managing the COVID-19 pandemic is not uniform. One of the main causes of this variation in efficiency is fluctuations in the number of cases reported in the health region. In addition, the results also revealed low levels of PTE in Saskatoon and Regina health regions for a few days. However, the obtained PTE means and medians were above 0.75 for all six regions, with the Far North health region showing the lowest values (mean = 0.77, median = 0.85), and the Saskatoon and North regions showing the highest PTE mean (mean = 0.94) and median (median = 0.97) values, respectively. Interestingly, compared to the Saskatoon health region, the Regina region had a relatively low PTE. The differences observed in the PTEs of the two urban regions confirm that resources and infrastructure are not being uniformly distributed in the province.



(a) (b) (c)

Figure 3: Pure Technical Efficiency (PTE) of the six health regions in Saskatchewan.

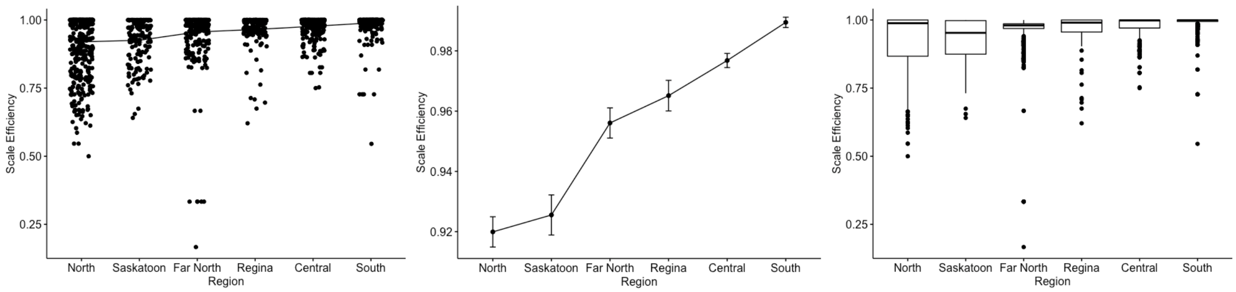
The results for the OTEs of the six analyzed health regions are shown in Figure 4, which depicts the scatter plot with means (a), means and standard errors (b), and box plots with the medians, upper and lower quartiles, and whiskers indicating variability outside the upper and lower quartiles (c). Once again, the results showed very high day-to-day variability in the Far North region's OTE, as well as high overall day-to-day variability in OTEs of the other five regions. This high day-to-day variability indicates that the province's health units are not efficiently utilizing their inputs on a day-to-day basis, which may be due to fluctuations in the number of cases reported in each health region. A large amount of variation is once again seen in the three rural health regions (North, Central and South) of the province. The findings also revealed low OTE levels in Saskatoon and Regina for a few days.



(a) (b) (c)

Figure 4: Overall Technical Efficiency (OTE) of six health regions in Saskatchewan.

Figure 5 shows the scatter plot with means (a), means and standard errors (b), and box plots showing the medians, upper and lower quartiles, and the whiskers indicating variability outside the upper and lower quartiles (c), for the SE for all the six regions of Saskatchewan. The spread (day-to-day variation) in the SE is not as high as the spreads in PTE and OTE observed in Figures 4-5. The narrower spread is also evident in the low range of medians (0.95 for Saskatoon to 1.00 for Central and South health regions) for the SEs of all six health regions. The high SE values for all six health regions indicates that their scale of operations is optimal given their input resources. A comparison of the means and standard errors of the SEs for all six health regions revealed that North and Saskatoon regions had SE values below 0.94, while the other four regions (Far North, Regina, Central, and South) had SE values above 0.94. The Central and South health regions not only had the highest SE values, but they also had the lowest day-to-day spread of SE, which indicates that their scale of operations is consistently optimal.



(a) (b) (c)

Figure 5: Scale Efficiency (SE) of six health regions in Saskatchewan.

The meta-frontier and the group frontiers of the health regions analyzed in this study are plotted in Figure 7. Although, the meta-frontier envelops all of the group frontiers representing Saskatchewan’s different health regions, on its own it does not provide a complete picture of how well the province’s health sectors have handled COVID-19 affected patients. As shown in Figure 6, the group frontier for the Saskatoon health region is the closest to the meta frontier, while the group frontiers of the South and the Central health regions are the farthest from it. This result clearly indicates that the Saskatoon health region has performed better than the others in handling COVID-19 patients, likely due to both urban health regions having better input resources. However, the comparison of the meta-frontier with the health regions’ group frontiers clearly shows that more input resources need to be diverted to the province’s rural health regions in order to provide better, uniform and equitable health services.

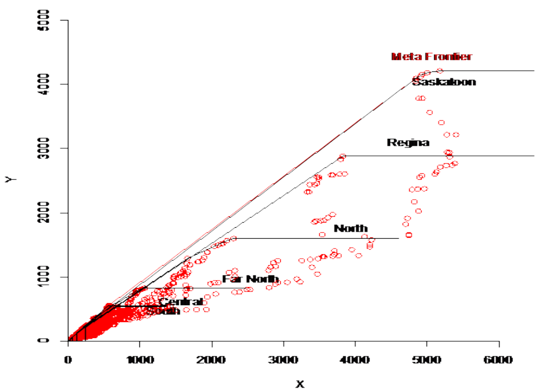


Figure 6: Meta-frontier analysis of the six health regions in Saskatchewan

Figure 7 shows a comparison of the efficiency frontiers of the individual health regions and their sub-regions in Saskatchewan. The group frontiers of Saskatoon and Regina indicate that these regions are not operating efficiently on most days, as their scatter plots deviate from the efficiency frontier, which is shown by the solid line. Therefore, these regions must manage inputs more efficiently in order to improve recovery rates for COVID-19 patients. Similarly, the Far North West region had the highest efficiency among the sub-regions of the Far North health region, followed by the Far North East and the Far North Central regions. For the Central health region, a higher efficiency rate was observed in the Central East region compared to the Central West region. Finally, the South West region had the highest efficiency of the sub-regions in the South health region, followed by South Central and South East regions. This comparison of the efficiencies of each of the province’s health sub-regions was only possible via meta-frontier analysis, as it enables the identification of resource-availability gaps in each sub-region.

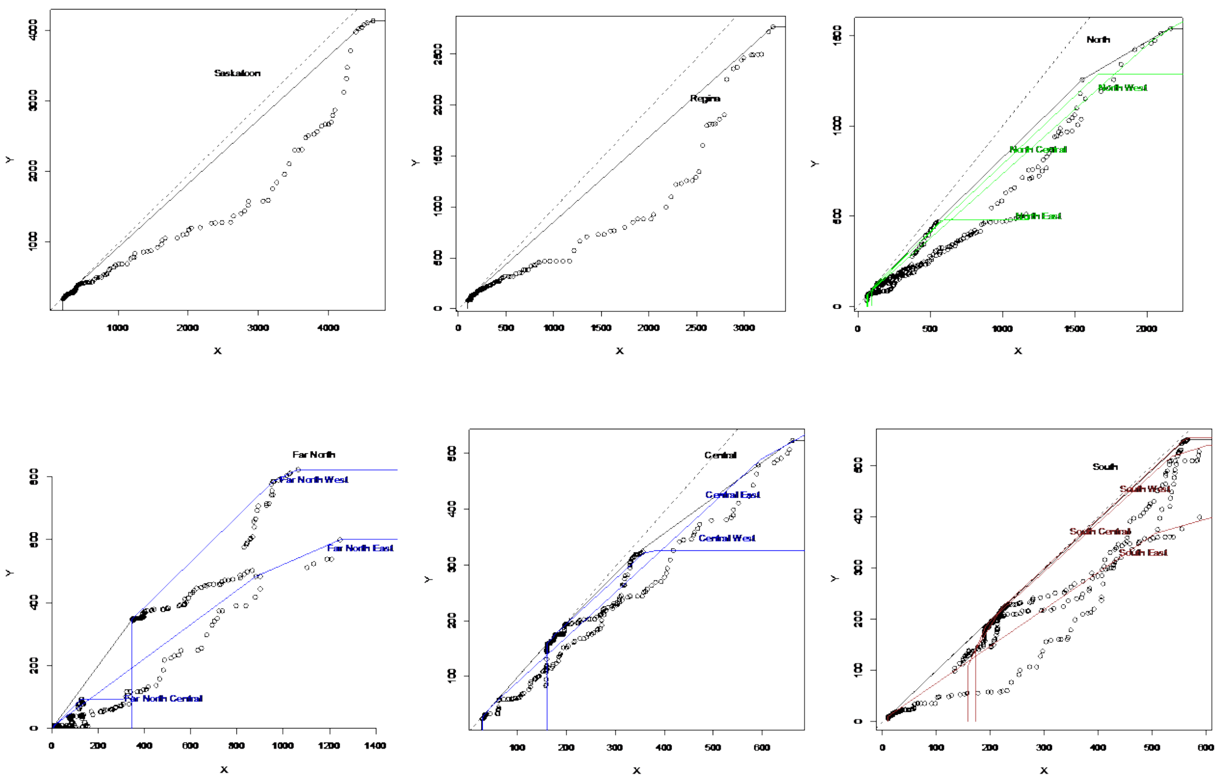


Figure 7: Individual group frontier analysis of the six health regions with their sub-regions. Dotted line is for the Constant Returns to Scale (CRS) technology.

6. Managerial Implications

The Saskatchewan Health Authority, which includes all of the province's health regions, coordinates health services across the province to ensure patients receive high-quality and timely health care, irrespective of the health region they live in. In addition, the Saskatchewan Health Authority administers health-promotion and disease-prevention programs across the province through the health units in each region. These health units also focus on a variety of non-pharmaceutical interventions, including testing, contact tracing, and isolating infected cases, in addition to treating confirmed cases of COVID-19. The results of this study provide important information that identifies inefficient health regions, and that can be used to advocate for equitable access to health care for COVID-infected individuals in the province's rural and remote regions.

The results of this study showed that all six health regions had higher PTE compared to OTE with respect to their handling of COVID-confirmed cases, which indicates that the province's health regions have handled the pandemic well from a managerial point of view, but not in terms of the effective utilization of resources. The findings also showed high day-to-day variability in the Far North region with respect to PTE and OTE. The Far North region of the province is sparsely populated, mainly consisting of rural and remote areas, and equipped with very few health care units. Significantly, we also observed a large degree of variation in the day-to-day relative efficiencies of the province's other three rural health regions (North, Central, and South). Thus, it is evident that Saskatchewan's rural and remote regions lack the resources and infrastructure needed to manage a high volume of COVID-19 cases; this poses a significant danger, as it limits these health authorities' ability to prevent the disease from spreading into communities in these regions. The Saskatchewan Health Authority works on the principle of health equity, which implies that all people in the province should have equal access to full health care, and should not be prevented from attaining it due to their geographic location or socioeconomic status. As such, the Saskatchewan Health Authority should develop policies aimed at eliminating any health inequities for populations living in rural and remote areas, as these inequities are often the result of unfair and unequal life chances and barriers to health, social, and economic systems. The Saskatchewan Health Authority should collaborate with community partners and other government organizations to close the health-disparity gap in rural and remote regions.

Finally, benchmarking the efficient health units in each health region can help managers understand the best practices for effectively treating confirmed cases, and provide insights into how inefficient health units can become more efficient. Moreover, benchmarking helps to identify internal opportunities for improvement. Analysing how certain health units achieve superior performance and comparing their processes with those of inefficient health units can help managers identify and implement changes that can yield significant improvements. This approach can also help managers in setting goals regarding changes in the productivity of the health units. Benchmarking also enhances healthcare workers' familiarity with the key performance metrics, and provides opportunities for continuous improvement across the health regions.

The results of our study provide policy makers and Saskatchewan Health Authority management with comprehensive details and managerial insights that will allow them to more efficiently allocate future resources in order to improve the performance of health units in Saskatchewan. Nonetheless, these results must be interpreted with caution, as the DEA methodology has some limitations. For instance, the complete weight flexibility in the evaluation of DEA efficiency scores, may lead to a health unit with an extreme weighting scheme being identified as efficient. The DEA methodology may also inappropriately screen out candidates from benchmarking based on the specified combinations of inputs and outputs. This may result in a health unit not being selected as a benchmark, despite performing well with respect to the overall inputs and outputs. Therefore, this study's results in relation to relative efficiencies should be considered alongside the measurements of some key financial performance indicators in the decision-making process.

7. Conclusion

In this paper, the non-parametric bootstrap DEA methodology was employed to analyze the relative efficiencies with which Saskatchewan's regional health authorities have handled the COVID-19 pandemic. In doing so, we analyzed pure technical efficiency, overall technical efficiency, and scale efficiency. To conduct our analysis, we condensed Saskatchewan's health regions into six larger health regions (Far North, North, Central excluding Saskatoon, Saskatoon, South excluding Regina, and Regina). Our results show that the province of Saskatchewan has not been able to manage COVID-19-infected patients adequately, largely due to the ineffective utilization of resources. In addition, the results showed a large amount of variation in the day-to-day relative efficiencies in the province's rural and remote health regions, which may be due to a lack of resources and infrastructure required to manage a high volume of infected cases. This result is particularly concerning, as the inability to adequately deal with an influx of COVID-19-related cases in remote and rural areas may inhibit the ability of these health authorities to prevent the community spread of the disease. We further identified the health sub-regions that can act as benchmarks for the other sub-regions to follow in improving their own relative efficiencies.

The results of this study are limited by the lack of available input and output data. We used data that were publicly available. More comprehensive input and output data (including population demographics, and social and economic indicators in the various health regions) could yield more in-depth results. Nonetheless, the results of this study provide interesting insights that can be used to develop policies aimed at eliminating healthcare inequities for populations living in different regions. These policies should be predicated on collaborations with community partners and government organizations in order to close the health-disparity gaps in relation to health promotion, protection and disease prevention. Future research in this area should include more inputs and outputs, and should undertake comparisons of public-health units in different Canadian provinces in order to continue to develop the most effective management strategies possible for dealing with future pandemics.

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