Dynamic Performance Assessment of Hospitals by Applying Credibility-Based Fuzzy Window Data Envelopment Analysis

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Abstract: The goal of the current research is to propose the credibility-based fuzzy window data envelopment analysis (CFWDEA) approach as a novel method for the dynamic performance evaluation of hospitals during different periods under data ambiguity and linguistic variables. To reach this goal, a data envelopment analysis (DEA) method, a window analysis technique, a possibilistic programming approach, credibility theory, and chance-constrained programming (CCP) are employed. In addition, the applicability and efficacy of the proposed CFWDEA approach are illustrated utilizing a real data set to evaluate the performance of hospitals in the USA. It should be explained that three inputs including the number of beds, labor-related expenses, patient care supplies, and other expenses as well as three outputs including the number of outpatient department visits, the number of inpatient department admissions, and overall patient satisfaction level, are considered for the dynamic performance appraisal of hospitals. The experimental results show the usefulness of the CFWDEA method for the evaluation and ranking of hospitals in the presence of fuzzy data, linguistic variables, and epistemic uncertainty.

Keywords: hospital performance assessment; data envelopment analysis; window analysis; fuzzy optimization; linguistic variables; credibility theory

1. Introduction

The hospital, as one of the most important and main parts of the health care system, has a prominent and significant role in the performance of health care networks [1–5]. As observed during the coronavirus pandemic, the quality level of hospital performance had a remarkable effect on patient mortality rate. Thus, proposing an effective method to assess the performance and productivity of hospitals is one of the most important issues in health care literature [6–13]. Data envelopment analysis (DEA) is one of the popular and applicable non-parametric mathematical programming methods that are widely employed by many researchers in the health care field to appraise the productivity and performance of hospitals and their departments [14–24]. DEA is one of the most powerful and effective multi criteria decision making (MCDM) approaches for performance assessment, benchmarking, and ranking the peer decision-making units (DMUs) in the presence of multiple inputs and outputs. Furthermore, DEA is capable of identifying the efficient frontier (EF) of a production possibility set (PPS). The EF represents the maximal output attainable from each input level [25–29].

Figure 1 illustrates the EF and PPS, where one input and one output are considered. Based on the DEA approach, the DMUs E, J, G, and B are technically efficient whereas the DMUs C, A, H, D, I, and F are technically inefficient in Figure 1.
Notably, one of the main problems and issues in the performance assessment of hospitals in real-life case studies is to identify the trend and the effect of time variations as well as the dynamic changes in the performance level of each hospital over time periods. In addition, some of the variables, such as overall patient satisfaction level as an important criterion for hospital performance appraisal, are linguistic variables that can be converted to fuzzy variables. Since the conventional and traditional DEA models are not capable of being applied under a panel data and fuzzy environment, proposing, and applying new data envelopment analysis models that can measure the dynamic performance of hospitals under data ambiguity during different periods seems to be essential.

Accordingly, in this research, the credibility-based fuzzy window data envelopment analysis (CFWDEA) approach is presented for the dynamic performance appraisal of hospitals over time under linguistic variables and data ambiguity. It should be explained that to propose the CFWDEA method, data envelopment analysis, window analysis, possibilistic programming, credibility theory, and chance-constrained programming (CCP) are applied. Moreover, the proposed CFWDEA approach is implemented in a real-life case study for assessing the dynamic performance of six hospitals in the USA during six different periods.

The rest of this paper is organized as follows. The applications of the window data envelopment analysis (WDEA) method in the health care field, as well as literature gaps, are presented in Section 2. Then, the credibility-based fuzzy window DEA approach for the dynamic performance appraisal of hospitals in the presence of linguistic variables and fuzzy panel data are proposed in Section 3. Furthermore, the proposed CFWDEA approach is applied to a real-world case study and the experimental results are analyzed in Section 4. Finally, conclusions as well as some suggestions and directions for future research are introduced in Section 5.

2. Literature Review

In this section, the literature review of window data envelopment analysis applications in health care systems is presented. Moreover, the literature research gaps, which this study addresses, are introduced. Accordingly, the characteristics of window DEA studies in health care area including the basic DEA model, the case study, the application location, and the data type are presented in Table 1.
Table 1. The application of window DEA approach in health care systems: a literature review.

| Year   | Research                        | DEA Model | Case Study (Location)          | Data Type |
|--------|---------------------------------|-----------|--------------------------------|-----------|
| 2004   | Gannon [30]                     | CCR *     | Hospital (Ireland)             | Crisp     |
| 2005   | Ozcan et al. [31]               | BCC *     | Mental Health Service (USA)    | Crisp     |
| 2009   | Kazley and Ozcan [32]           | CCR       | Hospital (USA)                 | Crisp     |
| 2009   | Weng et al. [33]                | CCR       | Hospital (USA)                 | Crisp     |
| 2017   | Flokou et al. [34]              | BCC       | Public Hospital Sector (Greece)| Crisp     |
| 2017   | Jia and Yuan [35]               | BCC       | Multi-Branced Hospital (China) | Crisp     |
| 2017   | Klangrahad [36]                 | BCC       | Hospital (Thailand)            | Crisp     |
| 2017   | Mirmozaffari and Alinezhad [37] | Two-Stage | Heart Hospital (Iran)          | Crisp     |
| 2018   | Pirani et al. [38]              | BCC       | Public Hospital (Iran)         | Crisp     |
| 2018   | Serván-Mori et al. [39]         | BCC       | Maternal Health Service (México)| Crisp     |
| 2018   | Steflko et al. [40]             | CCR       | Regional Health Care (Slovakia)| Crisp     |
| 2019   | Fuentes et al. [41]             | CCR       | Public Hospital (Spain)        | Crisp     |
| 2019   | Kocisova et al. [42]            | CCR       | Regional Health Care (Slovakia)| Crisp     |
| 2019   | Serván-Mori et al. [43]         | BCC       | Maternal Health Service (México)| Crisp     |
| 2021   | Andrews [44]                    | BCC       | Health Board (New Zealand)     | Crisp     |
| 2021   | Miszczynska and Miszczyński [45]| CCR       | Health Care System (Poland)    | Crisp     |
| 2022   | Yüksel [46]                     | CCR       | Health Care System (OECD)      | Crisp     |
| 2022   | Vatková and Vrábková [47]       | CCR       | Hospital (Czech and Slovakia)  | Crisp     |

The Current Research | Fuzzy DEA | Hospital (USA) | Uncertain

* CCR: Charnes, Cooper, and Rhodes [25]; BCC: Banker, Charnes, and Cooper [26].

As summarized in Table 1, all the existing window DEA studies are implemented in health care systems and omit the uncertainty of data. As a result, presenting an effective and novel approach that is capable of being applied for the dynamic performance assessment of hospitals during different periods under data ambiguity and linguistic variables is needed. Thus, as is seen in the last row of Table 1, in this research, the credibility-based fuzzy window DEA approach is proposed to evaluate the dynamic performance of hospitals in the presence of fuzzy panel data.

3. The Proposed Approach

In this section, the credibility-based fuzzy window data envelopment analysis approach is proposed step by step. It should be explained that at the first step, the classic DEA model under constant returns to scale (CRS) assumption is introduced. Then, using window analysis method, the traditional DEA model is developed under panel data. In the following, the window DEA model is prepared for considering ambiguity in all inputs and outputs. Finally, possibilistic programming, credibility theory, and chance-constrained programming are utilized to present the CFWDEA approach that is capable of being used in the presence of fuzzy panel data. The methodology of the paper is illustrated in Figure 2.

Now, according to Figure 3, suppose that there are \( N \) homogeneous decision-making units \( DMU_j (j = 1, 2, \ldots, N) \) that convert \( M \) inputs \( x_{ij} (i = 1, 2, \ldots, M) \) into \( S \) outputs \( y_{rj} (r = 1, 2, \ldots, S) \). In addition, the non-negative weights \( P_i \) and \( Q_r \) are assigned to inputs and outputs, respectively.

The efficiency score of specific \( DMU_d \) that is an under evaluation DMU, can be measured by applying the following linear problem. It should be noted that Model (1) is called the multiplier form of input oriented CCR model [25].

\[
\text{Max} \quad \sum_{r=1}^{S} y_{rd} Q_r
\]

\[
\text{S.t.} \quad \sum_{r=1}^{S} y_{rj} Q_r - \sum_{i=1}^{M} x_{ij} P_i \leq 0, \quad \forall j
\]

\[
\sum_{i=1}^{M} x_{id} P_i = 1
\]

\[
P_i, Q_r \geq 0, \quad \forall i, r
\]

Notably, by combining window analysis method and DEA model, the window DEA approach can be obtained that is capable to be used for dynamic performance evalua-
tion of DMUs under panel data and different periods [48–52]. To present the WDEA model, suppose that all homogenous decision-making units DMU \(_j (j = 1, 2, \ldots, N)\) are observed in \(\delta(t = 1, 2, \ldots, \delta)\) periods. Furthermore, let \(k_z\) denote the window start in period \(k (1 \leq k \leq \delta)\) with width \(z (1 \leq z \leq \delta - k)\). It should be explained that the number of windows \((a)\), the number of different DMUs per window \((\beta)\), and the total number of different DMUs \((\lambda)\) are calculated by \(a = \delta - z + 1, \beta = zN\), and \(\lambda = a\beta\), respectively [53]. Accordingly, the window DEA approach for dynamic performance measurement of DMU\(_{dk_z}\) is introduced as Model (2).

\[
\begin{align*}
\text{Max} & \quad \sum_{r=1}^{S} y_{rdk_z} Q_r \\
\text{S.t.} & \quad \sum_{r=1}^{S} y_{rjk_z} Q_r - \sum_{i=1}^{M} x_{ijk_z} P_i \leq 0, \quad \forall j \\
& \quad \sum_{i=1}^{M} x_{idk_z} P_i = 1 \\
& \quad P_i, Q_r \geq 0, \quad \forall i, r
\end{align*}
\]

Now, assume that the inputs and outputs of window DEA approach are tainted by uncertainty. It is noteworthy that triangular fuzzy number (TRFN) and trapezoidal fuzzy number (TLFN) are the most popular and applicable fuzzy number in fuzzy mathematical field. Figure 4 presents the membership function curve of TRFN \(f(f^{(1)}, f^{(2)}, f^{(3)})\), \(f^{(1)} \leq f^{(2)} \leq f^{(3)}\) and TLFN \(g(g^{(1)}, g^{(2)}, g^{(3)}, g^{(4)}), g^{(1)} \leq g^{(2)} \leq g^{(3)} \leq g^{(4)}\).

**Figure 2.** The schematic summary of all steps in the proposed CFWDEA approach.
To deal with the uncertainty of inputs and outputs, the objective function is converted into constraint. In addition, an equal constraint become a less than or equal constraint [54–57]. By assuming the fuzzy inputs and fuzzy outputs have a trapezoidal distribution $\tilde{x}_{ij}(x_{ij}^{(1)}, x_{ij}^{(2)}, x_{ij}^{(3)}, x_{ij}^{(4)})$ and $\tilde{y}_{ij}(y_{ij}^{(1)}, y_{ij}^{(2)}, y_{ij}^{(3)}, y_{ij}^{(4)})$ in which $x_{ij}^{(1)} \leq x_{ij}^{(2)} \leq x_{ij}^{(3)} \leq x_{ij}^{(4)}$ and $y_{ij}^{(1)} \leq y_{ij}^{(2)} \leq y_{ij}^{(3)} \leq y_{ij}^{(4)}$, the uncertain window data envelopment analysis (UWDEA) model under fuzzy panel data can be considered as Model (3).

$$\text{Max } G$$

subject to

$$\sum_{r=1}^{S} \tilde{y}_{rjkz} Q_{r} \geq G$$

$$\sum_{r=1}^{S} \tilde{y}_{rjkz} Q_{r} - \sum_{i=1}^{M} \tilde{x}_{ijkz} P_{i} \leq 0, \quad \forall j$$

$$\sum_{i=1}^{M} \tilde{x}_{idkz} P_{i} \leq 1$$

$$P_{i}, Q_{r} \geq 0, \quad \forall i, r$$

In order to deal with data uncertainty in constraints, credibility-based fuzzy chance-constrained programming (CFCCCP) approach is used [58–65]. Let $\tilde{\omega}$ be a trapezoidal fuzzy variable on the possibility space $(\Phi, P(\Phi), Pos)$ and $\phi$ be a crisp number. According to the
CFCCP approach, the credibility \( Cr \) of fuzzy events \( \{ \tilde{\omega} \leq \phi \} \) and \( \{ \tilde{\omega} \geq \phi \} \) at the desired confidence level \( \xi \) are presented in Equations (4) and (5), respectively.

\[
Cr\{ \tilde{\omega} \leq \phi \} \geq \xi \iff \begin{cases} 
(1 - 2\xi)\omega^{(1)} + 2\xi\omega^{(2)} \leq \phi & \text{if } \xi \leq 0.5; \\
(2 - 2\xi)\omega^{(3)} + (2\xi - 1)\omega^{(4)} \leq \phi & \text{if } \xi > 0.5. 
\end{cases}
\] (4)

\[
Cr\{ \tilde{\omega} \geq \phi \} \geq \xi \iff \begin{cases} 
2\xi\omega^{(3)} + (1 - 2\xi)\omega^{(4)} \geq \phi & \text{if } \xi \leq 0.5; \\
(2\xi - 1)\omega^{(1)} + (2 - 2\xi)\omega^{(2)} \geq \phi & \text{if } \xi > 0.5. 
\end{cases}
\] (5)

As it can be seen in Equations (4) and (5), for the confidence levels of greater or less than 0.5, an equivalent crisp of fuzzy chance constraints (FCC) would be different. Now, by applying CFCCP approach, the credibility-based fuzzy window DEA model for \( \xi \leq 0.5 \) and \( \xi > 0.5 \) are defined as Models (6) and Model (7), respectively.

\[
\text{Max } \underline{C} \\
\text{S.t. } \sum_{r=1}^{S} \left( (2\xi - 1)y_{r,dkc}^{(1)} + (2 - 2\xi)y_{r,dkc}^{(2)} \right) Q_{r} \geq \underline{C} \\
\sum_{r=1}^{S} \left( (2\xi - 1)y_{r,jk}^{(1)} + (2 - 2\xi)y_{r,jk}^{(2)} \right) Q_{r} - \sum_{i=1}^{M} \left( (2\xi - 1)x_{i,jk}^{(1)} + (2 - 2\xi)x_{i,jk}^{(2)} \right) P_{i} \leq 0, \ \forall j \\
\sum_{i=1}^{M} \left( (2\xi - 1)x_{i,dkc}^{(1)} + (2 - 2\xi)x_{i,dkc}^{(2)} \right) P_{i} \leq 1 \\
P_{i}, Q_{r} \geq 0, \ \forall i, r
\] (6)

\[
\text{Max } \overline{C} \\
\text{S.t. } \sum_{r=1}^{S} \left( (2\xi - 1)y_{r,dkc}^{(3)} + (2 - 2\xi)y_{r,dkc}^{(4)} \right) Q_{r} \geq \overline{C} \\
\sum_{r=1}^{S} \left( (2\xi - 1)y_{r,jk}^{(3)} + (2 - 2\xi)y_{r,jk}^{(4)} \right) Q_{r} - \sum_{i=1}^{M} \left( (2\xi - 1)x_{i,jk}^{(3)} + (2 - 2\xi)x_{i,jk}^{(4)} \right) P_{i} \leq 0, \ \forall j \\
\sum_{i=1}^{M} \left( (2\xi - 1)x_{i,dkc}^{(3)} + (2 - 2\xi)x_{i,dkc}^{(4)} \right) P_{i} \leq 1 \\
P_{i}, Q_{r} \geq 0, \ \forall i, r
\] (7)

Notably, since TRFN is a special case of TLFN, the proposed credibility-based fuzzy window DEA approach can be easily used in the presence of triangular fuzzy data.

4. Case Study and Experimental Results

In this section, the implementation of the proposed CFWDEA approach for a real-world case study is introduced. Accordingly, a real data set related to six hospitals from the USA for six different periods (2010–2015) is extracted. The inputs and outputs of the CFWDEA approach for hospital dynamic performance evaluation are presented in Figure 5 and Table 2.

It should be explained that all input and output data except the overall patient satisfaction are crisp values. The overall patient satisfaction level is reported with linguistic variables and their equivalent fuzzy numbers are introduced in Table 3 [66]. Finally, by setting the width of the window to three periods, the results of the credibility-based fuzzy window DEA approach for different confidence levels, including 0%, 20%, 40%, 60%, 80%, and 100% are reported in Tables 4–9, respectively.
Figure 5. The inputs and outputs of CFWDEA model for health care case study.

Table 2. Description and statistical information of research variables.

| Variables | Description                                      | Min    | Max    |
|-----------|--------------------------------------------------|--------|--------|
| Inputs    |                                                  |        |        |
| TNB       | The Number of Beds                               | 49     | 90     |
| LRE       | Compensation of Medical Doctors, Salaries and Wages of Non-Medical Doctors, Non-Payroll Labor, and Fringe Benefits | 3,778,001 | 9,202,308 |
| PCSOE     | Drugs, Medical Supplies, Food and Food Service Supplies, and Other Supplies and Expenses | 2,036,342 | 4,741,523 |
| Outputs   |                                                  |        |        |
| TNODV     | The Number of Patients that Not Require Hospital Admission | 35,649 | 78,483 |
| TNIDA     | The Number of Patients that Require Hospital Admission | 3476  | 7574  |
| OPSL      | The Feedback and Opinion of Patient about the Provided Services | VL     | VH     |

Table 3. The linguistic variables and their associated trapezoidal fuzzy number.

| Linguistic Variable | Trapezoidal Fuzzy Number |
|---------------------|--------------------------|
| Very Low            | (0, 0, 0.1, 0.2)         |
| Low                 | (0.1, 0.2, 0.2, 0.3)     |
| Medium Low          | (0.2, 0.3, 0.4, 0.5)     |
| Medium              | (0.4, 0.5, 0.5, 0.6)     |
| Medium High         | (0.5, 0.6, 0.7, 0.8)     |
| High                | (0.7, 0.8, 0.8, 0.9)     |
| Very High           | (0.8, 0.9, 0.9, 1)       |

Table 4. The results of dynamic performance assessment of hospitals (confidence level = 0%).

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
| Hospital 1| Window 1| 0.69954  | 1.60000  | 1.28571  |          |          |          | 1.19509 |
|           | Window 2| 1.49822  |          | 0.95784  | 1.25000  |          |          | 1.23535 |
|           | Window 3|          | 0.95784  | 1.25000  | 0.62459  |          |          | 0.94414 |
|           | Window 4| 1.54911  | 1.06713  | 1.25000  | 0.61719  | 0.87440  |          | 0.91387 |
|           | Average | 0.69954  | 1.54911  | 1.06713  | 1.25000  | 0.62089  | 0.87440  | 1.01018 |
| Hospital 2| Window 1| 0.85771  | 0.62875  | 0.71094  | 1.24585  | 0.81288  | 0.83861  | 0.83200 |
|           | Window 2| 0.76536  | 0.77909  | 0.84856  | 0.81288  | 0.83861  |          | 0.79767 |
|           | Window 3| 0.78860  | 0.90136  | 0.81288  | 0.83861  |          |          | 0.83428 |
|           | Window 4| 0.84450  | 0.81288  | 0.83861  |          |          |          | 0.83200 |
|           | Average | 0.85771  | 0.69706  | 0.75954  | 0.86481  | 0.81288  | 0.83861  | 0.80510 |
| Hospital 3| Window 1| 0.90842  | 0.88028  | 0.83627  | 0.87135  | 0.67136  | 0.92485  | 0.87499 |
|           | Window 2| 0.70965  | 0.69628  | 0.87135  | 0.67136  | 0.92485  |          | 0.75909 |
|           | Window 3| 0.81856  | 1.05776  | 0.65933  | 0.92485  |          |          | 0.84923 |
|           | Window 4| 1.05776  | 0.65933  | 0.92485  |          |          |          | 0.88065 |
|           | Average | 0.90842  | 0.79497  | 0.78370  | 0.99563  | 0.66534  | 0.92485  | 0.84548 |
### Table 4. Cont.

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
| Hospital 4 | Window 1 | 1.09588  | 1.28005  | 0.55113  | 0.97569  |          |          | 0.97569 |
|           | Window 2 | 0.93733  | 0.66966  | 0.67735  | 0.76155  |          |          | 0.76155 |
|           | Window 3 | 0.70903  | 0.70578  | 1.17396  | 0.86292  |          |          | 0.86292 |
|           | Window 4 | 0.70578  | 0.70578  | 1.17396  | 0.89116  | 0.92363  |          | 0.92363 |
|           | Average  | 1.09588  | 1.10869  | 0.64337  | 0.69630  | 1.17396  | 0.89116  | 0.93849 |
| Hospital 5 | Window 1 | 0.77416  | 0.62891  | 0.86885  | 0.75731  |          |          | 0.75731 |
|           | Window 2 | 0.70416  | 0.71245  | 1.00862  | 0.80481  |          |          | 0.80481 |
|           | Window 3 | 0.78428  | 0.70097  | 0.70191  | 0.81391  |          |          | 0.81391 |
|           | Window 4 | 1.00862  | 0.70191  | 0.73921  | 0.81627  |          |          | 0.81627 |
|           | Average  | 0.77416  | 0.66653  | 0.78852  | 1.17396  | 0.73921  | 0.7983  | 0.7983  |
| Hospital 6 | Window 1 | 0.70281  | 1.54583  | 0.97302  | 1.07389  |          |          | 1.07389 |
|           | Window 2 | 1.31824  | 0.74550  | 0.68100  | 0.91491  |          |          | 0.91491 |
|           | Window 3 | 0.76689  | 0.76689  | 0.85136  | 0.80020  | 0.77586  |          | 0.77586 |
|           | Window 4 | 0.76689  | 0.76689  | 0.85136  | 0.70932  |          |          | 0.70932 |
|           | Average  | 0.70281  | 1.43204  | 0.83362  | 0.87790  |          |          | 0.87790 |

### Table 5. The results of dynamic performance assessment of hospitals (confidence level = 20%).

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
| Hospital 1 | Window 1 | 0.69760  | 1.40741  | 1.15082  | 1.14286  | 1.14286  | 0.61972  | 0.94344 |
|           | Window 2 | 1.36173  | 0.88692  | 1.14286  | 0.62459  |          |          | 1.13050 |
|           | Window 3 | 0.88107  | 1.14286  | 0.62459  | 0.86885  |          |          | 0.88284 |
|           | Window 4 | 0.74550  | 0.68100  | 0.62459  | 0.94344  |          |          | 0.86689 |
|           | Average  | 0.69760  | 1.38457  | 0.92923  | 0.94344  |          |          | 0.94344 |
| Hospital 2 | Window 1 | 0.76599  | 0.58971  | 0.66467  |          |          |          | 0.67346 |
|           | Window 2 | 0.58971  | 0.76536  | 0.84586  |          |          |          | 0.79767 |
|           | Window 3 | 0.78860  | 0.90136  | 0.80334  |          | 0.79675  | 0.9409  | 0.83110 |
|           | Window 4 | 0.84149  | 0.68100  | 0.80334  | 0.79675  |          |          | 0.81361 |
|           | Average  | 0.76599  | 0.67754  | 0.74412  | 0.79675  |          |          | 0.77513 |
| Hospital 3 | Window 1 | 0.84930  | 0.78614  | 0.74684  | 0.91871  | 0.79675  |          | 0.86789 |
|           | Window 2 | 0.78614  | 0.90136  | 0.80334  | 0.91871  |          |          | 0.86789 |
|           | Window 3 | 0.80875  | 1.02819  | 0.95105  | 0.91871  |          |          | 0.86789 |
|           | Window 4 | 0.74370  | 0.80334  | 0.79675  |          |          |          | 0.81339 |
|           | Average  | 0.84930  | 0.74370  | 0.74992  | 0.79675  |          |          | 0.81339 |
| Hospital 4 | Window 1 | 0.97566  | 1.17815  | 0.51691  | 0.79675  | 0.79675  |          | 0.80724 |
|           | Window 2 | 0.85698  | 0.64963  | 0.64963  | 0.79675  |          |          | 0.72553 |
|           | Window 3 | 0.70903  | 0.69538  | 0.70933  | 0.79675  |          |          | 0.82592 |
|           | Window 4 | 0.69538  | 0.70933  | 0.79675  |          |          | 0.82592  | 0.88135 |
|           | Average  | 0.97566  | 1.01756  | 0.63197  | 0.79675  |          |          | 0.87566 |
| Hospital 5 | Window 1 | 0.72663  | 0.58830  | 0.77593  | 0.79675  | 0.79675  |          | 0.77854 |
|           | Window 2 | 0.70306  | 0.71038  | 0.92217  | 0.79675  |          |          | 0.80011 |
|           | Window 3 | 0.77532  | 0.92217  | 0.72842  | 0.79675  |          |          | 0.78384 |
|           | Window 4 | 0.77532  | 0.92217  | 0.70049  | 0.79675  |          |          | 0.74667 |
|           | Average  | 0.72663  | 0.64568  | 0.75388  | 0.79675  |          |          | 0.74667 |
| Hospital 6 | Window 1 | 0.70096  | 1.35977  | 0.88505  | 0.98199  |          |          | 0.98199 |
|           | Window 2 | 1.21642  | 0.67758  | 0.87699  | 0.85767  |          |          | 0.85767 |
|           | Window 3 | 0.75422  | 0.75772  | 0.84120  | 0.78438  |          |          | 0.78438 |
|           | Window 4 | 0.75772  | 0.84120  | 0.70724  | 0.76872  |          |          | 0.76872 |
|           | Average  | 0.70096  | 1.28820  | 0.77228  | 0.84023  |          |          | 0.84023 |
### Table 6. The results of dynamic performance assessment of hospitals (confidence level = 40%).

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
| Hospital 1 | Window 1 | 0.69760  | 1.24138  | 1.02792  |          |          |          | 0.98897 |
|           | Window 2 | 1.22791  | 0.82422  | 1.09454  | 0.62459  |          |          | 1.04889 |
|           | Window 3 | 0.83853  | 1.09454  | 1.09303  | 0.61271  |          |          | 0.85255 |
|           | Window 4 | 1.09454  | 1.09404  | 0.89689  |          |          |          | 0.84405 |
|           | Average  | 0.69760  | 1.23465  | 0.89689  | 1.09404  | 0.61865  |          | 0.89471 |
| Hospital 2 | Window 1 | 0.71131  | 0.58787  | 0.62037  |          |          |          | 0.63985 |
|           | Window 2 | 0.76536  | 0.77909  | 0.84856  |          |          |          | 0.79767 |
|           | Window 3 | 0.78860  | 0.90136  | 0.79434  |          |          |          | 0.82810 |
|           | Window 4 | 0.83877  | 0.79434  | 0.76787  | 0.76787  |          |          | 0.80032 |
|           | Average  | 0.71131  | 0.67662  | 0.72935  | 0.86290  | 0.76787  |          | 0.75706 |
| Hospital 3 | Window 1 | 0.79269  | 0.73003  | 0.69353  |          |          |          | 0.73875 |
|           | Window 2 | 0.70845  | 0.69227  | 0.76802  |          |          |          | 0.72291 |
|           | Window 3 | 0.79928  | 0.99947  | 0.67136  |          |          |          | 0.82337 |
|           | Window 4 | 0.99947  | 0.65444  | 0.91313  | 0.85568  |          |          | 0.78977 |
|           | Average  | 0.79269  | 0.71924  | 0.72836  | 0.92232  | 0.66290  | 0.91313  | 0.82472 |
| Hospital 4 | Window 1 | 0.87205  | 1.08181  | 0.51384  |          |          |          | 0.82257 |
|           | Window 2 | 0.78525  | 0.66996  | 0.64775  | 0.70099  |          |          | 0.79521 |
|           | Window 3 | 0.70903  | 0.68752  | 0.98909  | 0.86502  |          |          | 0.84721 |
|           | Window 4 | 0.68752  | 0.98909  | 0.86502  |          |          |          | 0.78977 |
|           | Average  | 0.87205  | 0.93353  | 0.63095  | 0.67427  | 0.98909  | 0.86502  | 0.82748 |
| Hospital 5 | Window 1 | 0.68342  | 0.58320  | 0.72055  |          |          |          | 0.66239 |
|           | Window 2 | 0.70845  | 0.70852  | 0.84498  |          |          |          | 0.75218 |
|           | Window 3 | 0.76719  | 0.86784  | 0.70284  | 0.79299  |          |          | 0.73602 |
|           | Window 4 | 0.86784  | 0.69559  | 0.69921  | 0.72565  | 0.72395  |          | 0.72395 |
|           | Average  | 0.68342  | 0.64313  | 0.73209  | 0.69221  | 0.69921  | 0.72565  | 0.72395 |
| Hospital 6 | Window 1 | 0.69947  | 1.19964  | 0.80189  |          |          |          | 0.90033 |
|           | Window 2 | 1.12348  | 0.63971  | 0.67718  | 0.81346  |          |          | 0.80831 |
|           | Window 3 | 0.73975  | 0.74888  | 0.83139  | 0.77334  |          |          | 0.76188 |
|           | Window 4 | 0.74888  | 0.83139  | 0.70537  | 0.76188  |          |          | 0.77334 |
|           | Average  | 0.69947  | 1.16156  | 0.72712  | 0.83139  | 0.70537  |          | 0.80831 |

### Table 7. The results of dynamic performance assessment of hospitals (confidence level = 60%).

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
| Hospital 1 | Window 1 | 0.69760  | 1.00190  | 0.80556  |          |          |          | 0.83502 |
|           | Window 2 | 1.00190  | 0.71833  | 1.09243  | 0.62459  |          |          | 0.93755 |
|           | Window 3 | 0.82086  | 1.09243  | 1.09234  | 0.60742  | 0.79939  |          | 0.84596 |
|           | Window 4 | 1.08775  | 0.60742  | 0.61016  | 0.79939  |          |          | 0.83152 |
|           | Average  | 0.69760  | 1.00190  | 0.78158  | 1.09087  | 0.61016  | 0.79939  | 0.83122 |
| Hospital 2 | Window 1 | 0.63949  | 0.58787  | 0.60378  |          |          |          | 0.61038 |
|           | Window 2 | 0.76536  | 0.77909  | 0.84856  |          |          |          | 0.79767 |
|           | Window 3 | 0.78860  | 0.90136  | 0.77940  | 0.79407  |          |          | 0.82312 |
|           | Window 4 | 0.83388  | 0.77940  | 0.74863  | 0.73821  | 0.79407  |          | 0.78730 |
|           | Average  | 0.63949  | 0.67662  | 0.72382  | 0.86127  | 0.77940  | 0.74863  | 0.73821 |
| Hospital 3 | Window 1 | 0.77150  | 0.65632  | 0.62351  |          |          |          | 0.68378 |
|           | Window 2 | 0.70845  | 0.68832  | 0.76802  | 0.61016  | 0.80911  |          | 0.72159 |
|           | Window 3 | 0.78390  | 0.96738  | 0.65255  | 0.89908  | 0.83967  |          | 0.79407 |
|           | Window 4 | 0.96738  | 0.65255  | 0.66195  | 0.89908  | 0.83967  |          | 0.79407 |
|           | Average  | 0.77150  | 0.68239  | 0.69858  | 0.90249  | 0.66195  | 0.89908  | 0.76933 |
### Table 7. Cont.

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
|           | Window 1 | 0.66585  | 0.88611  | 0.51384  |          |          |          | 0.68860 |
| Hospital 4| Window 2 | 0.69212  | 0.66996  | 0.64347  | 0.49284  |          |          | 0.77043 |
|           | Window 3 | 0.70903  | 0.67378  | 0.67378  | 0.92760  | 0.84895  |          | 0.81678 |
|           | Window 4 | 0.66585  | 0.78911  | 0.63095  | 0.66367  | 0.92804  | 0.84895  | 0.75443 |
| Hospital 5| Window 1 | 0.57909  | 0.58320  | 0.64780  |          |          |          | 0.60336 |
|           | Window 2 | 0.70306  | 0.70920  | 0.72061  | 0.68444  |          |          | 0.70986 |
|           | Window 3 | 0.75944  | 0.83786  | 0.70284  |          |          |          | 0.76665 |
|           | Window 4 | 0.83786  | 0.68944  | 0.71322  |          |          |          | 0.74678 |
| Hospital 6| Window 1 | 0.69899  | 0.90918  | 0.61228  |          |          |          | 0.74015 |
|           | Window 2 | 0.94415  | 0.63280  | 0.67358  | 0.80667  | 0.70318  |          | 0.75017 |
|           | Window 3 | 0.71553  | 0.73910  | 0.73910  | 0.80667  | 0.70318  |          | 0.74965 |
|           | Window 4 | 0.73910  | 0.80667  | 0.70318  | 0.80667  | 0.70318  |          | 0.75105 |

### Table 8. The results of dynamic performance assessment of hospitals (confidence level = 80%).

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average |
|-----------|---------|----------|----------|----------|----------|----------|----------|---------|
|           | Window 1 | 0.69760  | 1.00190  | 0.73585  |          | 1.09102  |          | 0.81178 |
| Hospital 1| Window 2 | 1.00190  | 0.71181  | 1.09102  | 0.62459  |          |          | 0.93491 |
|           | Window 3 | 0.80431  | 0.90136  | 0.77393  | 0.78590  | 0.70318  |          | 0.83997 |
|           | Window 4 | 1.08277  | 1.08827  | 0.60583  | 0.78497  | 0.70318  |          | 0.82603 |
|           | Average  | 0.69760  | 1.00190  | 0.75065  | 1.08827  | 0.61521  | 0.78497  | 0.82385 |
|           | Window 1 | 0.60773  | 0.58787  | 0.60321  |          |          |          | 0.59960 |
| Hospital 2| Window 2 | 0.76356  | 0.77909  | 0.84856  | 0.77393  | 0.73845  | 0.78209  | 0.77967 |
|           | Window 3 | 0.76860  | 0.90136  | 0.72393  | 0.78590  | 0.70318  |          | 0.82130 |
|           | Window 4 | 0.83388  | 0.77393  | 0.77393  | 0.73845  | 0.78209  |          | 0.77967 |
|           | Average  | 0.60773  | 0.67662  | 0.72363  | 0.86127  | 0.77393  | 0.73845  | 0.73027 |
|           | Window 1 | 0.77076  | 0.62373  | 0.59254  |          | 0.56802  | 0.67136  | 0.86127  | 0.83597 |
| Hospital 3| Window 2 | 0.68730  | 0.76746  | 0.96174  | 0.65255  | 0.89908  | 0.89908  | 0.76341 |
|           | Window 3 | 0.76966  | 0.96174  | 0.65255  | 0.89908  | 0.89908  |          | 0.76341 |
|           | Window 4 | 0.66155  | 0.66155  | 0.88419  | 0.88419  |          |          | 0.73213 |
|           | Average  | 0.63418  | 0.68413  | 0.63095  | 0.66155  | 0.88419  | 0.88419  | 0.73213 |
|           | Window 1 | 0.57905  | 0.58320  | 0.61563  |          | 0.64347  | 0.68771  | 0.59262  | 0.69989 |
| Hospital 5| Window 2 | 0.70306  | 0.70903  | 0.80979  | 0.70284  |          |          | 0.75590 |
|           | Window 3 | 0.75505  | 0.80979  | 0.68913  | 0.71020  | 0.70284  | 0.75590  | 0.73638 |
|           | Window 4 | 0.57905  | 0.64313  | 0.69219  | 0.69599  | 0.71020  | 0.71020  | 0.68161 |
|           | Average  | 0.57905  | 0.58320  | 0.61563  | 0.64347  | 0.68771  | 0.68771  | 0.59262  |
|           | Window 1 | 0.69899  | 0.89414  | 0.58315  |          |          |          | 0.72543 |
| Hospital 6| Window 2 | 0.94415  | 0.63096  | 0.67309  |          |          |          | 0.74940 |
|           | Window 3 | 0.70689  | 0.73466  | 0.80667  | 0.70318  | 0.70318  | 0.70318  | 0.74941 |
|           | Window 4 | 0.73466  | 0.80667  | 0.70318  | 0.70318  | 0.70318  | 0.70318  | 0.74817 |
|           | Average  | 0.69899  | 0.91914  | 0.64033  | 0.71414  | 0.80667  | 0.80667  | 0.74708 |
Table 9. The results of dynamic performance assessment of hospitals (confidence level = 100%).

| Hospitals | Windows | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 | Average  |
|-----------|---------|----------|----------|----------|----------|----------|----------|----------|
| Hospital 1 | Window 1 | 0.69760  | 1.00190  | 0.70248  | 0.80066  | 0.61521  | 0.78435  | 0.80066  |
|           | Window 2 | 0.70787  | 1.00190  | 0.70248  | 0.80066  | 0.61521  | 0.78435  | 0.93339  |
|           | Window 3 | 0.78884  | 1.09102  | 0.62459  | 0.83482  | 0.78435  | 0.82269  | 0.81979  |
|           | Window 4 | 0.69760  | 1.00190  | 0.7306   | 0.61521  | 0.78435  | 0.81979  | 0.81979  |
|           | Average  |          |          |          |          |          |          |          |
| Hospital 2 | Window 1 | 0.59238  | 0.58787  | 0.60321  | 0.59449  | 0.79767  | 0.72530  |          |
|           | Window 2 | 0.76536  | 0.77909  | 0.8456   | 0.79767  | 0.72530  |          |          |
|           | Window 3 | 0.78860  | 0.90136  | 0.7692   | 0.81973  | 0.72530  |          |          |
|           | Window 4 | 0.83388  | 0.8388   | 0.7692   | 0.72530  |          |          |          |
|           | Average  | 0.59238  | 0.67662  | 0.72363  | 0.86127  | 0.78266  | 0.77225  | 0.75300  |
| Hospital 3 | Window 1 | 0.77076  | 0.59200  | 0.57577  | 0.64168  | 0.72126  | 0.80341  | 0.83597  |
|           | Window 2 | 0.70845  | 0.68730  | 0.7680   | 0.64168  | 0.72126  |          |          |
|           | Window 3 | 0.77173  | 0.96714  | 0.67136  | 0.80341  | 0.83597  |          |          |
|           | Window 4 | 0.95626  | 0.65255  | 0.69908  | 0.89908  |          |          |          |
|           | Average  | 0.77076  | 0.65022  | 0.67827  | 0.89908  | 0.89908  |          | 0.75957  |
| Hospital 4 | Window 1 | 0.60370  | 0.72576  | 0.51384  | 0.61443  | 0.72126  | 0.77444  | 0.71237  |
|           | Window 2 | 0.68530  | 0.66996  | 0.64347  | 0.66624  | 0.74315  |          |          |
|           | Window 3 | 0.70903  | 0.67118  | 0.8492   | 0.74315  | 0.77444  |          |          |
|           | Window 4 | 0.69908  | 0.89908  | 0.8293   | 0.77444  |          |          |          |
|           | Average  | 0.60370  | 0.70553  | 0.63095  | 0.8293   | 0.8293   |          | 0.71237  |
| Hospital 5 | Window 1 | 0.57905  | 0.58320  | 0.58431  | 0.58219  | 0.69798  | 0.75158  | 0.73276  |
|           | Window 2 | 0.70306  | 0.70590  | 0.68497  | 0.69798  | 0.75158  |          |          |
|           | Window 3 | 0.75294  | 0.79896  | 0.7028   | 0.75158  | 0.73276  |          |          |
|           | Window 4 | 0.79896  | 0.69913  | 0.7102   | 0.75158  | 0.73276  |          |          |
|           | Average  | 0.57905  | 0.64313  | 0.68105  | 0.7102   | 0.7102   |          | 0.67840  |
| Hospital 6 | Window 1 | 0.69899  | 0.89366  | 0.55470  | 0.71578  | 0.74880  | 0.74639  | 0.74668  |
|           | Window 2 | 0.94415  | 0.62916  | 0.67309  | 0.74880  | 0.74639  |          |          |
|           | Window 3 | 0.70230  | 0.73019  | 0.80667  | 0.74880  | 0.74639  |          |          |
|           | Window 4 | 0.73019  | 0.80667  | 0.70318  | 0.74880  | 0.74639  |          |          |
|           | Average  | 0.69899  | 0.91890  | 0.62872  | 0.70318  | 0.70318  |          | 0.74460  |

Notably, since the width of the window is set to three periods, the number of windows, the number of different hospitals per window, and the total number of different hospitals are calculated as $\alpha = 6 - 3 + 1 = 4$, $\beta = 3 \times 6 = 18$, and $\lambda = 4 \times 18 = 72$, respectively. As is seen in Tables 4–9, by increasing the confidence level from 0% to 100%, the results of the credibility-based fuzzy window DEA approach are decreased. Note that in addition to measuring the performance score of each hospital per window, three types of average scores, including the average performance scores of hospitals for all periods, the average performance scores of hospitals for all windows, and the average of all performance scores for each hospital are calculated. The total average results of all hospitals based on the CFWDEA approach are reported in Figure 6.

As can be seen in Figure 6, the full ranking of hospitals is obtained as Hospital 1, Hospital 4, Hospital 6, Hospital 3, Hospital 2, and Hospital 5, respectively. It is noteworthy that the highest efficiency score for all hospitals in all periods is obtained for Hospital 1 in Period 2. An examination of the data shows that the minimum amount of labor-related expenses ($\times 2$) as well as patient care supplies and other expenses ($\times 3$) for all hospitals in all periods is related to Hospital 1 in Period 2, which is equal to 3,778,001 and 2,036,342, respectively. Since Hospital 1 has the best overall performance in comparison with the other hospitals over a time horizon, the performance and planning of this hospital can be analyzed to be the benchmark for other hospital managements.
5. Conclusions and Future Research Directions

So far, various types of data including crisp data versus uncertain data (stochastic, fuzzy, interval, and mixed), cross-sectional data versus panel data, and quantitative data versus linguistic data have been used in the performance evaluation of hospitals. In this study, using a DEA model, a window analysis method, and credibility-based fuzzy chance-constrained programming, a novel and effective method is presented to evaluate the dynamic performance of hospitals in the presence of fuzzy panel data. Since utilizing linguistic variables allows the patients to easily represent their opinion about the provided services, the overall patient satisfaction is recorded with linguistic variables. The main advantages of the proposed CWFDEA approach can be mentioned as follows: the linearity of the mathematical models, the capability to fully rank all hospitals under data ambiguity, and the ability to examine the dynamic changes of the performance of each hospital over a time horizon. Moreover, implementation of the CWFDEA approach can increase the discrimination power by increasing the number of hospitals when a limited number of hospitals is available. For the future research, a robust optimization approach [67–73], uncertain theory [74–78], and Z-number theory [79–85] can be utilized in order to deal with data uncertainty.

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