mathematics

MDPI

Article

Using Weighted Data Envelopment Analysis to Measure Occupational Safety and Healthy Economic Performance of Taiwan's Industrial Sectors

Li-Ting Yeh

Department of Cooperative Economics and Social Entrepreneurship, Feng Chia University, No. 100 Wenhwa Rd, Seatwen Taichung 40724, Taiwan; lityeh@fcu.edu.tw; Tel.: +886-424517250 (ext. 4355)

Received: 31 August 2020; Accepted: 21 September 2020; Published: 22 September 2020

check for updates

Abstract: The socioeconomic costs of occupational accidents represent an important factor in the safety and healthy development of a country's economy. Insurance payments (which cover workplace incidents, such as wounds or illness, disability and fatality) can be considered a proxy for the socioeconomic cost of occupational accidents. Occupational accidents in different industries cause important variations in these three socioeconomic costs—for example, in their frequency and severity. One of the most commonly used mathematical programming approaches that analyze the performance of inputs, economic outputs and occupational accidents is data envelopment analysis (DEA), which has also been used in recent years to estimate the relative performance related to occupational injuries. This study measures the safety and healthy economic performance of Taiwan's 17 industrial sectors by incorporating the varying importance of the three socioeconomic costs of occupational accidents into a weighted DEA Model. The empirical results demonstrate that integrating the varying importance of the three socioeconomic costs of occupational accidents in the evaluation of safety and healthy economic performance is very important. To improve the occupational safety and healthy economic performance of Taiwan's main industrial sectors, efforts should focus on reducing fatalities, which are very costly. These findings could help Taiwan's policy makers effectively improve their safety and healthy economic performance, based on the specific context of each industry, especially the mining and quarrying industry.

Keywords: data envelopment analysis; occupational injury; occupational safety and healthy economic performance; socioeconomic costs; undesirable output

1. Introduction

Industrial occupational accidents are important factors to consider in the safety and healthy development of a country's economy [1,2] because occupational injuries can result in considerable socioeconomic costs [3,4]. Some of these costs can usually be identified as economic costs, such as lost workdays or medical costs, while other costs are difficult to quantify monetarily, such as negatively affected market goodwill [5]. Occupational accidents have been acknowledged to have a major impact on economic costs [1], and to lead to enormous economic costs, thereby inhibiting economic growth and affecting a country's competitiveness [3,6]. Thus, the socioeconomic costs of occupational accidents are considered to be an undesirable (unwelcome) output in the development of safety and health economic activities, and they negatively impact safety and healthy economic performance.

In general, insurance payment amounts can be regarded as a proxy for the socioeconomic costs of occupational accidents. Labor insurance is mandatory in Taiwan and is managed and operated by the government. It aims to protect the livelihoods of employees and their families and to promote social security. Injured employees might be permanently unable to work or to work for the same remuneration as earned prior to the injury, and they might experience either a complete loss of economic income or a disruption to their lives. Thus, Taiwan's labor insurance provides benefits to employees injured in an occupational accident. These benefits can be categorized based on three severity levels, which are wounds or illness benefits, disability benefits and fatality benefits, and these benefits are payable in cash. The loss of income associated with wounds or illness can be reimbursed via cash payments, and the cash benefits paid after a disability are based on the severity of the occupational injury. If an employee dies because of an occupational injury or illness, his or her family may be able to obtain death benefits. Taiwan's labor insurance also provides cash benefits when an employee is incapacitated due to an occupational accident. Compared to those of other countries, the Taiwanese government's legislative and regulatory policies on occupational health and safety are relatively weak [7]. The Taiwanese government is seeking more effective strategies for managing and improving the safety and healthy economic performance of major industrial sectors.

Performance measurements constitute an important task in strategic planning, and they are performed to better understand the various resource inputs and economic outputs of a decision-making unit (DMU), such as an organization or a firm, and to plan an improvement strategy [8,9]. Among these measures, data envelopment analysis (DEA), which is a mathematical programming approach, has been widely used to measure the relative performances of DMUs, such as industrial sectors (e.g., in [2,10,11]) or departments (e.g., in [12]). In general, DEA automatically assigns weights to each input and/or output, which is one of its main advantages because the subjectivity of the performance assessment is reduced. However, weight restrictions represent management's preferences for the relative importance of various resource inputs or economic outputs. In addition, general DEA can be classified into radial or non-radial methods. Radial methods assume either an input or output orientation and thus focus on input-side or output-side performance, respectively. In specific, an input orientation analysis provides the information as to how much proportional decrease in inputs is necessary while maintaining current output levels for an inefficient DMU to become efficient. On the other hand, an output orientation provides the improvement strategy on how much proportional increase in outputs is necessary while maintaining the current levels of inputs for an inefficient DMU. Accordingly, many indirect methods have been proposed to incorporate undesirable outputs into either input-side or output-side performance. Although these indirect methods can reduce undesirable outputs to the greatest possible extent, they do not correspond to actual business activities [10]. In this situation, ascertaining the proportional adjustment of resource inputs, economic outputs and undesirable outputs may be impractical. The non-radial slack-based measure (SBM) proposed by Tone [13] can directly capture all aspects of performance. The SBM model also allows for the non-proportional adjustment of different resource inputs, economic outputs and undesirable outputs. Thus, the SBM model has a good ability to address undesirable outputs [14].

Because the occurrence of occupational injuries may be considered to be an undesirable output and a random event, performing analytical calculations based on a parametric approach is difficult. A non-parametric statistical approach allows random variations in input–output data [15]. Therefore, DEA has been widely used to estimate the relative performance related to occupational injuries [2,11,16,17]. Previous studies adopted the number or rate of occupational accidents as undesirable outputs, and these undesirable outputs were assigned equal weights regardless of the relative importance of occupational accidents in different industries. However, Liu et al. [18] showed that industry is related to the working environment and that different industries influence the volume of occupational diseases and injuries. For example, the construction sector is more responsible for fatal accidents than other industrial sectors due to unsafe working conditions and the inherently hazardous nature of construction work [19]. Thus, different industries have different numbers of occupational accidents, which differ in the degree of severity [2,20], thereby resulting in different socioeconomic costs and variations in the importance of the three socioeconomic costs. The proportion of socioeconomic costs can be used as a weight to represent the varying importance of different categories of occupational accidents in each industrial sector. Thus, considering the socioeconomic costs of occupational accidents in a study is advantageous because the differences among industrial sectors can be clearly defined by their cost proportions. To integrate the proportion of socioeconomic costs of occupational accidents into safety and healthy economic performance measurements of Taiwan's main industrial sectors, a weight must be assigned to each undesirable output rather than assigning weights through optimization. This method could represent a better approach to significantly improve the safety and healthy economic performance of Taiwan's main industrial sectors and reduce the costs of occupational injuries in a specific industrial sector because, as the proportion of socioeconomic costs increases, the number of accidents in this category increases.

The rest of this paper is arranged as follows. The next section reviews performance measurements. The proposed weighted SBM model is presented in Section 3, and how the model can be adopted to perform safety and healthy economic performance evaluations in subsequent studies is explained. The research sample and data collection are described in Section 4, and the empirical results and a discussion with respect to the safety and healthy economic performance of Taiwan's industrial sectors are provided. Finally, concluding remarks are presented in the last section.

2. Materials and Methods

2.1. General Data Envelopment Analysis (DEA)

The DEA approach is a good strategy tool that compares similar elements based on various resource inputs and produces economic outputs. This tool uses the ratio of total weighted economic outputs to total weighted resource inputs to generate a single measure of performance score (ρ). In this basic context of DEA, to be an efficient DMU means producing more economic outputs with a given level of resource inputs relative to other DMUs (output-oriented model) or, alternatively, using fewer resource inputs with a given level of economic output relative to other DMUs (input-oriented model). Thus, the efficient DMUs are obtained and used as benchmarks for comparison with other DMUs. These efficient DMUs are connected by a line called the efficient frontier. These DMUs on the efficient frontier have a performance score (ρ) of 1, whereas inefficient DMUs have a performance score (ρ) of less than 1 but greater than 0. An inefficient DMU can be improved by projection onto the efficient frontier. The disadvantage of the basic DEA model is that inefficient DMUs' resource inputs and economic outputs cannot be non-proportionally adjusted simultaneously, and the model cannot contain all slacks. Slacks can be estimated based on the differences between the inefficiency of a DMU and a benchmark DMU. The use of the SBM model can simultaneously deal with the resource input slack (excess) and economic output slack (shortfall) and projects each inefficient DMU to the furthest point on the efficient frontier in the sense that the performance scores (ρ) of the objective function are to be minimized by determining the maximum of all slacks.

The DEA approach usually assumes that more economic outputs with fewer resource inputs improve the performance of DMUs. Undesirable outputs have recently attracted considerable attention, and it is well known that they play a major role in performance measurement. The use of the general SBM model can simultaneously measure the total resource input, total economic output and total undesirable output slack variables. Thus, this model might be more suitable than other general models for considering undesirable outputs.

Industrial economic growth is accompanied by an increase in occupational injuries [1,21]. The socioeconomic costs of occupational accidents can negatively impact economic productivity [4,22], thereby negatively affecting the level of safety and healthy economic development [1]. The socioeconomic costs of occupational accidents can be considered to be an undesirable output y^u_{kj}.

This study assumes that J DMUs must be assessed. Each DMU $_j$ ($j = 1, \ldots, J$) has I resource inputs $x_{ij}(i = 1, \ldots, I)$, produces R economic outputs y^e_{rj} ($r = 1, \ldots, R$) and has K socioeconomic costs of occupational accidents y^u_{kj} ($k = 1, \ldots, K, K = 3$). Therefore, the safety and healthy economic performance score (ρ) is defined as follows.

$$\text{Minimize} \quad \rho = \frac{1 - \frac{1}{I}\left(\sum_{i=1}^{I} \frac{s_i^-}{x_{i0}}\right)}{1 + \frac{1}{R+K}\left(\sum_{r=1}^{R} \frac{s_r^e}{y_{r0}^e} + \sum_{k=1}^{K} \frac{s_k^u}{y_{k0}^u}\right)} \tag{1}$$

subject to

$$\sum_{j=1}^{J} \lambda_j x_{ij} + s_i^- = x_{i0} \tag{1a}$$

$$\sum_{j=1}^{J} \lambda_j y_{rj}^e - s_r^e = y_{r0}^e \tag{1b}$$

$$\sum_{j=1}^{J} \lambda_j y_{kj}^u + s_k^u = y_{k0}^u \tag{1c}$$

$$\lambda \geq 0, s^- \geq 0, s^e \geq 0, s^u \geq 0$$

where s_i^- is the slack in the ith resource input, s_r^{+g} is the slack in the rth economic output, and s_k^b is the slack in the kth socioeconomic cost of occupational accidents. In this general model, $0 < \rho^* \leq 1$, s_i^{-*}, s^e and $s^{u*} = 0$ and $\rho^* = 1$ are representative of DMU_0 with SBM efficiency.

The above model assigns a uniform weight ($\frac{1}{R+K}$) to undesirable outputs; however, their relative importance degrees may not be uniform. In reality, each industrial sector attributes varying importance to different categories of occupational accidents.

2.2. Incorporating the Socioeconomic Costs of Occupational Accidents into a Weighted DEA Model

The resource input and/or economic output weights are set exogenously and could reflect the actual variables to a degree of relative importance. A weighted SBM model assigns weights to the resource inputs and/or economic outputs that correspond to the relative importance degree of the variables based on the ratio of each socioeconomic cost divided by the sum of all DMU-socioeconomic costs. However, the relative importance degrees of undesirable outputs are usually ignored in most DEA studies.

The impacts of different occupational accidents with differing importance on safety and healthy economic performance should be addressed separately. Thus, the proportion of the socioeconomic costs of occupational accidents can be used as a weight to represent this varying importance of different categories of accidents. This study proposes an approach that directly incorporates the different proportions of socioeconomic costs of occupational accidents (PS_{k0}^u) as weights into the objective function of the SBM model.

$$\text{Minimize} \quad \rho = \frac{1 - \frac{1}{I}\left(\sum_{i=1}^{I} \frac{s_i^-}{x_{i0}}\right)}{1 + \frac{1}{R+K}\left(\sum_{r=1}^{R} \frac{s_r^e}{y_{r0}^e} + \sum_{k=1}^{K} PS_{k0}^u \times \frac{s_k^u}{y_{k0}^u}\right)} \tag{2}$$

Subject to

$$\sum_{j=1}^{J} \lambda_j x_{ij} + s_i^- = x_{i0} \tag{2a}$$

$$\sum_{j=1}^{J} \lambda_j y_{rj}^e - s_r^e = y_{r0}^e \tag{2b}$$

$$\sum_{j=1}^{J} \lambda_j y_{kj}^u + s_k^u = y_{k0}^u \tag{2c}$$

$$\lambda \geq 0, s^- \geq 0, s^e \geq 0, s^u \geq 0$$

This model provides the safety and healthy economic performance score ρ of industrial sectors, and the relative importance is based on the proportion of socioeconomic costs of occupational accidents (PS_{k0}^u).

This weighted SBM model implies that serious damage to the safety and healthy economic performance score (ρ) caused by a unit of socioeconomic cost (PS_{k0}^u) with a larger weight is greater than this damage caused by a socioeconomic cost (PS_{k0}^u) with a smaller weight. Thus, if policymakers wish to improve safety and healthy economic performance quickly, they should first focus on occupational accidents with larger weights.

In addition to estimating the safety and healthy economic performance score ρ in the above SBM model, the slack variable of socioeconomic costs of occupational accidents s_k^u is defined as the difference between an inefficient DMU and the benchmark. In particular, the slack ratio index of the socioeconomic costs of occupational accidents (SR_k^u) is calculated as the ratio of the excess socioeconomic costs of occupational accidents (s_k^u) to the actual socioeconomic costs of occupational accidents (y_{k0}^u).

$$SR_k^u = \frac{s_k^u}{y_{k0}^u} \tag{3}$$

Furthermore, the different proportions of the socioeconomic costs of occupational accidents (PS_{k0}^u) are calculated as follows:

$$PS_{k0}^u = \frac{y_{k0}^u}{\sum_{k=1}^{q} y_{k0}^u} \tag{4}$$

where $\sum_{k=1}^{q} y_{k0}^u$ indicates the total socioeconomic costs of occupational accidents, and PS_{k0}^u satisfies the condition $\sum_{k=1}^{q} PS_{k0}^u = 1$.

By multiplying the slack ratio index of the socioeconomic costs of occupational accidents (SR_k^u) (3) by the proportion of socioeconomic costs of occupational accidents (PS_{k0}^u) (4), this study can obtain an index called the slack share of the socioeconomic costs of occupational accidents (SS_{k0}^u).

$$SS_{k0}^u = SR_{k0}^u \times PS_{k0}^u = \frac{s_k^u}{y_{k0}^u} \times \frac{y_{k0}^u}{\sum_{k=1}^{q} y_{k0}^u} = \frac{s_k^u}{\sum_{k=1}^{q} y_{k0}^u} \tag{5}$$

This index (SS_{k0}^u) indicates the impact of the inefficiency slack variable (s_k^u) of each industrial sector on the total socioeconomic costs of occupational accidents.

3. Assessing the Safety and Healthy Economic Performance Scores of Taiwan's 17 Major Industrial Sectors

In this section, we examine the safety and healthy economic performance scores (ρ^*) calculated by Equations (1) and (2) by using data on the 17 industrial sectors in Taiwan in 2017.

Data Sources and Variables

The socioeconomic costs of occupational accidents are expressed by the amounts paid for three severity levels of occupational injury cash benefits (y^u) [23]. Taiwan's Bureau of Labor Insurance provides an employee with a cash benefit for a covered accident if an employee suffers an occupational wound or illness (y_1^u), disability (y_2^u) or fatality (y_3^u). The cash benefits for an occupational wound or illness (y_1^u) include the loss of earnings because of a temporary inability to work due to the wound or illness. Occupational disability cash benefits (y_2^u) consist of cash payments for a complete or partial inability to participate gainfully in the labor market due to disability. If an employee dies because of a work-related injury or illness, then his or her family may be able to obtain fatality cash benefits (y^u_3). The three socioeconomic costs of occupational accidents (y^u) are unwelcome by-products of economic outputs (y^e). The value of industrial production (y^e) measures the actual economic output for an industrial sector's production [24]. Thus, the three socioeconomic costs of occupational accidents (y^u) and the value of industrial production (y^e) are considered to be undesirable outputs and economic outputs, respectively.

To protect the health of an insured employee, Taiwan's Bureau of Labor Insurance also provides occupational disease prevention benefits (x_1), such as medical check-ups, to employees to prevent and treat occupational diseases in the early stages. Thus, the occupational disease prevention benefit input (x_1) can improve the socioeconomic costs of occupational accidents (y^u). In addition, labor is an important input for industrial production (y^e) [24]. This paper considers working hours (x_2) as an input rather than the number of employed laborers because working hours (x_2) can best explain the situation of the industrial economy. For example, an industrial economic downturn leads to a reduction in business operations, which subsequently slows the pace of work and reduces working hours (x_2). When the industrial economy shows a cyclical upturn, working hours (x_2) increase correspondingly [21]. Studies have also shown that an increase in working hours (x_2) leads to work-related fatigue, which is the key factor in increasing the socioeconomic costs of occupational accidents (y^u) [25].

This study assesses safety and healthy economic performance by using the above input and output variables from Taiwan's 17 major industrial sectors in 2017. Taiwan's 17 major industrial sectors were classified according to the Standard Industrial Classification system.

The amounts of benefits paid out for the three severity levels of occupational injury (y^u) plus occupational disease prevention benefits (x_1) were collected from official statistics provided by the Taiwan Ministry of Labor (http://statdb.mol.gov.tw/statis/), and the other variables were obtained from the Statistics Committee of the Directorate General of Budget, Accounting and Statistics, Executive Yuan of Taiwan (http://ebas1.ebas.gov.tw). These official records have been extensively adopted in academic research (e.g., in [2,7,11]).

4. Results and Discussion

The consumption of fixed capital (x), the gross value of industrial production (y^e) and three socioeconomic costs of occupational accidents (y^u) for Taiwan's 17 major industrial sectors in 2017 are summarized in Table 1. The findings in this table show that work is particularly dangerous for Taiwanese employees in the Manufacturing, Wholesale and Retail Trade, and Construction sectors; in these three sectors, the total amounts paid out for injury benefits were NT$ 9,401,027,891, NT$ 4,430,040,914 and NT$ 3,145,445,699, respectively, and these values all exceed the national average of NT$ 1,685,701,247. Past research has found that the possibility of different levels of injury severity for each occupational accident can be affected by different industrial working environments [26]. Thus, these three sectors may have different working environments with different hazards.

Table 1. Relative input and output data from 17 industrial sectors in 2017.

Industrial Sectors	Inputs		Economic Output	Undesirable Outputs			
	Occupational Disease Prevention Benefits (NT$) ($x_1$)	Total Working Hours (h/Month) (x_2)	Industrial Production Value (NT$ Millions) (y^e)	Amount of Wound or Illness Benefits (NT$) ($y_1^u$)	Amount of Disability Benefits (NT$) ($y_2^u$)	Amount of Fatality Benefits (NT$) ($y_3^u$)	Total Socioeconomic Costs of Occupational Accidents (NT$ 1000)
Mining and Quarrying	112,265	170.4	24,272	1,362,313	1,510,012	17,387,007	20,259,332
Manufacturing	215,388,251	175.8	18,313,507	924,362,144	1,558,214,203	6,918,451,544	9,401,027,891
Electricity and Gas Supply	1,400,023	176.5	702,902	5,219,281	18,503,800	99,806,470	123,529,551
Water Supply and Remediation Activities	1,602,151	167.8	247,876	23,435,998	38,870,495	144,704,864	207,011,357
Construction	4,281,146	163.8	1,373,575	536,755,395	576,576,308	2,032,113,996	3,145,445,699
Wholesale and Retail Trade	16,486,352	164.7	4,078,721	450,410,535	720,984,153	3,258,646,226	4,430,040,914
Transportation and Storage	1,979,576	172.1	1,269,344	239,088,140	345,520,485	1,334,737,686	1,919,346,311
Accommodation and Food Services	208,189	160.4	855,672	181,083,066	212,667,626	784,489,704	1,178,240,396
Information and Communication	209,122	162.7	931,214	37,468,506	87,154,012	607,805,505	732,428,023
Finance and Insurance	79,170	164.6	1,687,366	65,561,522	163,953,823	935,547,240	1,165,062,585
Real Estate Activities	63,225	169.1	1,787,797	32,587,311	67,805,810	310,184,421	410,577,542
Professional, Scientific and Technical Services	3,216,811	165.2	615,848	66,353,615	136,123,355	714,111,525	916,588,495
Support Service Activities	1,508,034	179.2	391,661	141,239,485	210,856,287	846,211,366	1,198,307,138
Education Services	82,921	132	847,437	30,383,770	93,502,649	357,100,981	480,987,400
Human Health and Social Work Services	20,951,497	166.8	866,299	95,450,851	172,227,925	742,031,046	1,009,709,822
Arts, Entertainment and Recreation	55,480	164.4	240,351	27,483,651	57,339,037	232,002,772	316,825,460
Other Services	867,485	180	669,773	195,181,309	393,878,417	1,412,473,553	2,001,533,279
Average	15,793,629.2941	166.7941	2,053,153.8235	179,613,346.5882	285,628,729.2353	1,220,459,170.9412	1,685,701,246.7647
Standard Deviation	51,782,401.5125	10.7407	4,290,705.5771	245,906,279.8081	383,953,994.4815	1,677,302,404.7800	2,296,980,624.2784

This paper proposes a weighted SBM model that directly incorporates the weights of the different proportions of the socioeconomic costs of occupational accidents (PS^{u}_{k0}) into objective function (2). Based on the data from Table 1, the weights for the different proportions of the socioeconomic costs of occupational accidents (PS^{u}_{k0}) can be obtained by using Equation (4) (see Table 2). The proportion of fatalities to socioeconomic costs (PS^{u}_{3}) is relatively large, whereas the proportion of wounds or illness to socioeconomic costs (PS^{u}_{1}) is relatively small. The proportion of fatalities to socioeconomic costs (PS^{u}_{3}) is larger than the proportions of other costs of occupational accidents, which indicates that fatality cash benefits (y^{u}_{3}) have a larger impact on the safety and healthy economic performance scores (ρ^{*}) of Taiwan's industrial sectors.

Table 2. Proportions of the socioeconomic costs of occupational accidents by industrial sector.

Industrial Sectors	**Weights**		
	Proportion of Wounds or Illness in Socioeconomic Costs (PS^{u}_{1})	**Proportion of Disabilities in Socioeconomic Costs (PS^{u}_{2})**	**Proportion of Fatalities in Socioeconomic Costs (PS^{u}_{3})**
Mining and Quarrying	6.7244%	7.4534%	85.8222%
Manufacturing	9.8326%	16.5749%	73.5925%
Electricity and Gas Supply	4.2251%	14.9792%	80.7956%
Water Supply and Remediation Activities	11.3211%	18.7770%	69.9019%
Construction	17.0645%	18.3305%	64.6050%
Wholesale and Retail Trade	10.1672%	16.2749%	73.5579%
Transportation and Storage	12.4567%	18.0020%	69.5413%
Accommodation and Food Services	15.3689%	18.0496%	66.5815%
Information and Communication	5.1157%	11.8993%	82.9850%
Finance and Insurance	5.6273%	14.0725%	80.3002%
Real Estate Activities	7.9369%	16.5147%	75.5483%
Professional, Scientific and Technical Services	7.2392%	14.8511%	77.9097%
Support Service Activities	11.7866%	17.5962%	70.6172%
Education Services	6.3170%	19.4397%	74.2433%
Human Health and Social Work Services	9.4533%	17.0572%	73.4895%
Arts, Entertainment and Recreation	8.6747%	18.0980%	73.2273%
Other Services	9.7516%	19.6788%	70.5696%
Average	9.3566%	16.3323%	74.3111%
Standard Deviation	0.0351	0.0306	0.0574

To illustrate the advantageous characteristics of the weighted SBM model, we compare its results with the results obtained by the general SBM model. Table 3 provides the results for the safety and healthy economic performance scores (ρ^{*}) of all the industrial sectors as calculated by the general SBM model and the weighted SBM model. For four industrial sectors with efficiency scores (ρ^{*}) equal to 1.0000 (i.e., the Manufacturing, Electricity and Gas Supply, Wholesale and Retail Trade, and Real Estate sectors), the results are the same for both models, which indicates that these four industrial sectors are not affected by the different proportions of socioeconomic costs of occupational accidents (PS^{u}_{k0}). This also means that these four sectors (with ρ^{*} = 1.0000) constitute the most efficient ones—i.e., the ones who are on the efficient frontier. In the other industrial sectors, for which the weights of the different proportions of socioeconomic costs of occupational accidents (PS^{u}_{k0}) are integrated, all the inefficient industrial sectors' safety and healthy economic performance scores (ρ^{*}) increase, and considerable changes occur. The safety and healthy economic performance score (ρ^{*}) is higher for the weighted SBM model than for the general SBM model because the weighted SBM model uses the different proportions of the socioeconomic costs of occupational accidents (PS^{u}_{k0}) as weights. Therefore, the weights of the different proportions of the socioeconomic costs of occupational accidents (PS^{u}_{k0}) on safety and healthy economic performance (ρ^{*}) are highly sensitive. The results showed that the SBM model, which took into account the weights of the different proportions of the socioeconomic costs of occupational accidents (PS^{u}_{k0}), led to improved efficiency scores (ρ^{*}), but they did not affect the relative efficiency rankings for most industrial sectors.

Table 3. Comparison of the general SBM model and the weighted SBM model.

Industrial Sectors	General SBM Model		Weighted SBM Model	
	Safety and Healthy Economic Performance Scores (ρ^*)	Rank	Safety and Healthy Economic Performance Scores (ρ^*)	Rank
Mining and Quarrying	0.0073	17	0.0089	17
Manufacturing	1.0000	1	1.0000	1
Electricity and Gas Supply	1.0000	1	1.0000	1
Water Supply and Remediation Activities	0.0463	16	0.0615	16
Construction	0.2385	7	0.3284	7
Wholesale and Retail Trade	1.0000	1	1.0000	1
Transportation and Storage	0.2183	9	0.2971	8
Accommodation and Food Services	0.1978	10	0.2689	10
Information and Communication	0.2379	8	0.2969	9
Finance and Insurance	0.5914	5	0.7385	5
Real Estate Activities	1.0000	1	1.0000	1
Professional, Scientific and Technical Services	0.1104	13	0.1483	13
Support Service Activities	0.0635	15	0.0877	15
Education Services	0.3377	6	0.4216	6
Human Health and Social Work Services	0.1530	11	0.1853	11
Arts, Entertainment and Recreation	0.0897	14	0.1208	14
Other Services	0.1117	12	0.1541	12
Average	0.3767		0.4187	
Standard Deviation	0.3803		0.3713	

This paper used the nonparametric statistical Wilcoxon matched pairs signed rank to test the null hypothesis. The empirical results show that the Z statistic is 3.3282 (the p-value is 0.0009) at a 1% significance level. Thus, the results permit a rejection of the null hypothesis that integrates the weights of the different proportions of socioeconomic costs of occupational accidents (PS_{k0}^{u}) into the safety and healthy economic performance score (ρ^*) measurement, which did not yield a significant difference. These results indicate that the different proportions of the socioeconomic costs of occupational accidents (PS_{k0}^{u}) are important for evaluating safety and healthy economic performance (ρ^*). The weighted restrictions allow for the integration of priorities or managerial preferences in terms of the relative importance degrees of various undesirable outputs. Therefore, the weighted SBM model is suitable for the framework of this study because it directly incorporates the weights of the different proportions of the socioeconomic costs of occupational accidents (PS_{k0}^{u}) into the objective function (2).

By focusing on the results of the weighted SBM model, this paper finds that the average safety and healthy economic performance score (ρ^*) of each industrial sector is approximately 0.4187. Specifically, the Mining and Quarrying industry has the lowest safety and healthy economic performance score ($\rho^* = 0.0089$). This result shows that Taiwan's Mining and Quarrying industry has more room to improve its safety and healthy economic performance. Table 4 indicates that the inefficient industrial sectors that require an adjustment in their safety and healthy economic performance (ρ^*) are determined by using the slack ratio index. For example, the Mining and Quarrying industry has the greatest slack ratio index for occupational disease prevention benefits (x_1). Taiwan's Mining and Quarrying industry involves numerous underlying hazards in the working environment. In a high-hazard working environment, many injuries result in disabilities or fatalities, and many occupational wounds or illnesses, such as chronic lung disease and hearing loss, are irreversible. Therefore, disease prevention (x_1) has become the principal safety and health objective for the Mining and Quarrying industry. Managers' attitudes towards accident prevention are vital in ensuring a safe working environment [5]. Tan et al. [20] also found that increasing both safety capital input and safety labor input constitutes the most important accident prevention approach to reduce occupational accidents in the mining industry.

Table 4. The slack ratio index for the resource inputs, economic outputs and three socioeconomic costs of occupational accidents.

Inefficient Industrial Sectors	Resource Inputs		Economic Output	Undesirable Outputs		
	Occupational Disease Prevention Benefits (NT$) ($x_1$)	Total Working Hours (h/Month) (x_2)	Industrial Production Value (NT$ Million) (y^e)	Amount of Wound or Illness Benefits (NT$) ($y_1^u$)	Amount of Disability Benefits (NT$) ($y_2^u$)	Amount of Fatality Benefits (NT$) ($y_3^u$)
Mining and Quarrying	99.2354%	98.6527%	0.0000%	67.5243%	39.0359%	75.7795%
Water Supply and Remediation Activities	99.4529%	86.0277%	0.0000%	80.7211%	75.8141%	70.2797%
Construction	98.8653%	20.6834%	0.0000%	95.3355%	90.9647%	88.2725%
Transportation and Storage	97.7323%	30.2372%	0.0000%	90.3228%	86.0667%	83.5000%
Accommodation and Food Services	85.4648%	49.5422%	0.0000%	91.3869%	84.7400%	81.0756%
Information and Communication	84.2522%	45.8639%	0.0000%	54.6984%	59.4761%	73.4181%
Finance and Insurance	24.6264%	3.0373%	0.0000%	53.0873%	60.9666%	68.7071%
Professional, Scientific and Technical Services	99.3230%	64.7395%	0.0000%	83.0824%	82.8411%	85.0373%
Support Service Activities	99.0815%	79.3273%	0.0000%	94.9454%	92.9551%	91.9697%
Education Services	63.8579%	39.2762%	0.0000%	49.1611%	65.6258%	58.8265%
Human Health and Social Work Services	83.3314%	78.9525%	0.0000%	0.0000%	11.2740%	6.9220%
Arts, Entertainment and Recreation	84.6792%	86.1717%	0.0000%	84.0595%	84.1019%	82.0256%
Other Services	97.2695%	64.8050%	0.0000%	93.7451%	93.5507%	91.7729%
Average	85.9363%	57.4859%	0.0000%	72.1592%	71.3394%	73.6605%
Standard Deviation	21.2212%	28.8207%	0.0000%	27.3589%	24.1346%	22.2534%

To improve the safety and healthy economic performance (ρ) of Taiwan's industrial sectors, the socioeconomic costs of fatalities (y_3^u) with greater weight should be adjusted first. This means that Taiwan's policy makers should focus on how to reduce fatalities, which are very costly. The major causes of occupational fatalities (y_3^u) in Taiwan's industrial sectors are related to unsafe working conditions, equipment issues, poor safety management and staff factors [27,28]. Occupational accidents can be reduced through a greater commitment from management, changes in working conditions and practices, investments in safety tools, and changes in equipment [29]. In addition, a number of staff factors, such as training, education and work-related mental stress, may affect these results. To reduce the socioeconomic costs of occupational accidents in Taiwan's industrial sectors, effective training and education should be provided to improve all employees' safety knowledge, safety attitudes and safety perceptions [6,30]. Work-related mental stress, such as poor attitudes, difficulty concentrating, sleep disorders, and difficulties related to co-workers, has a significant impact on workers' performance and represents a reason why personal safety is a major cause of occupational accidents [31]. The Taiwanese government has begun to plan strategies to address work-related mental stress [7], which should be expressly focused on the specific context of each industrial sector.

5. Conclusions

In various industries, occupational accidents can result in different levels of injury severity, thereby resulting in different degrees of importance for different accident categories. Unfortunately, this issue appears to be ignored by most researchers. This paper provides four major contributions. First, this study proposes an approach that directly incorporates the different proportions of the socioeconomic costs of occupational accidents as weights to represent the varying importance of different categories of occupational accidents in the objective function of the SBM model. Second, this paper discusses this approach, which involves using an empirical application to assess the safety and healthy economic performance of the 17 main industrial sectors in Taiwan. Third, the empirical results demonstrate that integrating the varying importance of the three socioeconomic costs of occupational accidents into the evaluation of safety and healthy economic performance is superior. Finally, this paper uses the slack ratio index provided by Taiwanese policy makers to improve safety and healthy economic performance based on the specific context of each industrial sector. Specifically, policy makers should focus on the Mining and Quarrying industry since the safety and healthy economic performance of this industrial sector is the lowest. These industries should reduce occupational disease prevention benefits to enhance their safety and healthy economic performance.

Although the resource inputs, economic outputs and three socioeconomic costs of occupational accidents were collected from two different government institutions to avoid the common variance problem, certain limitations and biases might be observed in the official records. For example, in Taiwan, labor insurance is provided to employers but is not provided to self-employed individuals, small enterprises or family workers [7]. In the future, panel analysis or other observations should be considered. For example, researchers should use the dynamic DEA framework (such as the Malmquist productivity index or dynamic SBM model) to estimate the changes in safety and healthy economic performance over long periods of time and should further investigate the effects of external factors on safety and healthy economic performance. Previous researchers have also confirmed that the incidence of occupational injuries varies throughout the business cycle [21].

Author Contributions: L.-T.Y. designed the study, analyzed the data, and wrote the manuscript. The author has read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Science and Technology—grant number MOST 106-2410-H-035 -011.

Acknowledgments: I wish to thank the Ministry of Science and Technology, Taiwan, which provided funding through contract MOST 106-2410-H-035-011.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Jilcha, K.; Kitaw, D. Industrial occupational safety and health innovation for sustainable development. *Eng. Sci. Technol. Int. J.* **2017**, *20*, 372–380. [CrossRef]
2. Yeh, L.T.; Tseng, M.L.; Lim, M.K. Assessing the carry-over effects of both human capital and organizational forgetting on sustainability performance using dynamic data envelopment analysis. *J. Clean. Prod.* **2020**, *250*, 119584. [CrossRef]
3. Lebeau, M.; Duguay, P.; Boucher, A. Costs of occupational injuries and diseases in Quebec. *J. Saf. Res.* **2014**, *50*, 89–98. [CrossRef] [PubMed]
4. Savall, H.; Zardet, V. *Mastering Hidden Costs and Socioeconomic Performance*; IAP: Charlotte, NC, USA, 2008.
5. Ismail, Z.; Kong, K.K.; Othman, S.Z.; Law, K.H.; Khoo, S.Y.; Ong, Z.C.; Shirazi, S.M. Evaluating accidents in the offshore drilling of petroleum: Regional picture and reducing impact. *Measurement* **2014**, *51*, 18–33. [CrossRef]
6. Pinto, A.; Nunes, I.L.; Ribeiro, R.A. Occupational risk assessment in construction industry–overview and reflection. *Saf. Sci.* **2011**, *49*, 616–624. [CrossRef]
7. Cheng, Y. Policy responses to work-related stress: Examining Taiwan's experiences from a welfare state regime perspective. *Saf. Sci.* **2015**, *78*, 111–116. [CrossRef]
8. Yeh, L.T.; Chang, D.S. Using categorical dea to assess the effect of subsidy policies and technological learning on R&D efficiency of it industry. *Technol. Econ. Dev. Econ.* **2019**, *26*, 311–330. [CrossRef]
9. Azadeh, A.; Sheikhalishahi, M. An efficient taguchi approach for the performance optimization of health, safety, environment and ergonomics in generation companies. *Saf. Health Work* **2015**, *6*, 77–84. [CrossRef]
10. Chang, D.S.; Kuo, L.C.R.; Chen, Y.T. Industrial changes in corporate sustainability performance–an empirical overview using data envelopment analysis. *J. Clean. Prod.* **2013**, *56*, 147–155. [CrossRef]
11. Yeh, L.T. Incorporating workplace injury to measure the safety performance of industrial sectors in Taiwan. *Sustainability* **2017**, *9*, 2241. [CrossRef]
12. Azadeh, A.; Salehi, V.; Mirzayi, M. The impact of redundancy and teamwork on resilience engineering factors by fuzzy mathematical programming and analysis of variance in a large petrochemical plant. *Saf. Health Work* **2016**, *7*, 307–316. [CrossRef] [PubMed]
13. Tone, K. A slacks-based measure of efficiency in data envelopment analysis. *Eur. J. Oper. Res.* **2001**, *130*, 498–509. [CrossRef]
14. Wang, C.-N.; Le, A.L.; Hou, C.-C. Applying undesirable output model to security evaluation of Taiwan. *Mathematics* **2019**, *7*, 1023. [CrossRef]
15. Desai, A.; Ratick, S.J.; Schinnar, A.P. Data envelopment analysis with stochastic variations in data. *Socio Econ. Plan. Sci.* **2005**, *39*, 147–164. [CrossRef]
16. Beriha, G.S.; Patnaik, B.; Mahapatra, S.S. Safety performance evaluation of Indian organizations using data envelopment analysis. *Benchmarking* **2011**, *18*, 197–220. [CrossRef]
17. Nissi, E.; Rapposelli, A. Analysing industrial accidents in European countries using data envelopment analysis. In *Social Exclusion*; Parodi, G., Sciulli, D., Eds.; Springer: Berlin/Heidelberg, Germany, 2012; pp. 93–101.
18. Liu, C.H.; Huang, C.Y.; Huang, C.C. Occupational neurotoxic diseases in Taiwan. *Saf. Health Work* **2012**, *3*, 257–267. [CrossRef]
19. Ranasinghe, U.; Jefferies, M.; Davis, P.; Pillay, M. Resilience engineering indicators and safety management: A systematic review. *Saf. Health Work* **2020**, *11*, 127–135. [CrossRef]
20. Tan, H.; Wang, H.; Chen, L.; Ren, H. Empirical analysis on contribution share of safety investment to economic growth: A case study of Chinese mining industry. *Saf. Sci.* **2012**, *50*, 1472–1479. [CrossRef]
21. Chang, D.S.; Chen, Y.; Tsai, Y.C. How injury incidence is associated with business cycles? Empirical evidence from Taiwan. *Saf. Sci.* **2018**, *110*, 235–248. [CrossRef]
22. McCaughey, D.; DelliFraine, J.L.; McGhan, G.; Bruning, N.S. The negative effects of workplace injury and illness on workplace safety climate perceptions and health care worker outcomes. *Saf. Sci.* **2013**, *51*, 138–147. [CrossRef]
23. Cheng, P.L.; Lin, H.Y.; Lee, Y.K.; Hsu, C.Y.; Lee, C.C.; Su, Y.C. Higher mortality rates among the elderly with mild traumatic brain injury: A nationwide cohort study. *Scand. J. Trauma Resusc. Emerg. Med.* **2014**, *22*, 7. [CrossRef] [PubMed]

24. Chen, L.; Jia, G. Environmental efficiency analysis of China's regional industry: A data envelopment analysis (DEA) based approach. *J. Clean. Prod.* **2017**, *142*, 846–853. [CrossRef]
25. Dembe, A.E.; Erickson, J.B.; Delbos, R.G.; Banks, S.M. The impact of overtime and long work hours on occupational injuries and illnesses: New evidence from the United States. *Occup. Environ. Med.* **2005**, *62*, 588–597. [CrossRef] [PubMed]
26. Ruser, J.W. Industry contributions to aggregate workplace injury and illness rate trends: 1992–2008. *Am. J. Ind. Med.* **2014**, *57*, 1149–1164. [CrossRef] [PubMed]
27. Cheng, C.W.; Leu, S.S.; Cheng, Y.M.; Wu, T.C.; Lin, C.C. Applying data mining techniques to explore factors contributing to occupational injuries in Taiwan's construction industry. *Accid. Anal. Prev.* **2012**, *48*, 214–222. [CrossRef]
28. Cheng, C.W.; Lin, C.C.; Leu, S.S. Use of association rules to explore cause–effect relationships in occupational accidents in the Taiwan construction industry. *Saf. Sci.* **2010**, *48*, 436–444. [CrossRef]
29. Beriha, G.S.; Patnaik, B.; Mahapatra, S.S.; Padhee, S. Assessment of safety performance in Indian industries using fuzzy approach. *Expert Syst. Appl.* **2012**, *39*, 3311–3323. [CrossRef]
30. Tam, C.M.; Zeng, S.X.; Deng, Z.M. Identifying elements of poor construction safety management in China. *Saf. Sci.* **2004**, *42*, 569–586. [CrossRef]
31. Idrees, M.D.; Hafeez, M.; Kim, J.Y. Workers' age and the impact of psychological factors on the perception of safety at construction sites. *Sustainability* **2017**, *9*, 745. [CrossRef]