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Incorporating Workplace Injury to Measure the Safety Performance of Industrial Sectors in Taiwan

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Abstract: The severity of workplace injuries varies by industry. Information on workplace injuries can enable firms and governments to effectively improve their safety performance based on the specific contexts of each industry. Incorporating the three workplace injury rates (being wounded or ill, disability, and death), a data envelopment analysis (DEA) model is developed to evaluate the safety performance of 17 industrial sectors in Taiwan. The results suggest that the Taiwanese government should pay particular attention to the mining and quarrying industry, which has the lowest safety performance. Additionally, the results provide abundant information for the Taiwanese government to design industry safety regulations in a way that may prompt firms to develop a sustainable economy by improving their health and safety practices and enhancing their overall safety performance.

Keywords: data envelopment analysis; undesirable output; workplace injury; safety performance

1. Introduction

Both in society and within firms, safety is becoming increasingly important for the development of a sustainable economy [1]. In 2015, 55,105 cases of workplace injuries (which include being wounded or ill, disability, and death) occurred in Taiwan, leading to the disbursement of labor insurance benefits. This sizable number of cases is far from the zero-accident goal for which the Industrial Safety and Health Association of the R.O.C Taiwan has campaigned since 2006. Thus, firms and the government face pressure to address these workplace injuries [2]. Workplace injuries can be used as a comparative measure of safety performance [3]. These injuries are considered an undesirable output in business operations and business activities that are detrimental to firms' productivity and business performance [4–7]. Workplace injuries negatively affect not only business activities [8], but also the competitiveness of countries [8,9]. Thus, investigating the safety performance of business operations is important for improving the strategies and policies to reduce workplace injuries.

Decision-making is the selection of a procedure that weighs alternatives and provides improved strategies for inefficient organizations [10]. Various mathematical approaches have been used to develop decision-making models. One such approach, data envelopment analysis (DEA), makes sense to consider the decision-making unit (DMU) as it uses fewer inputs for the same or higher levels of output to arrive at the same level of performance as a better performer. A growing body of research has used DEA to explore methods for assessing safety performance. For example, Hermans et al. [11] used the output-oriented Charnes-Cooper-Rhodes (CCR) model to evaluate road safety performance in countries and used the number of crashes and casualties as outputs. El-Mashaleh et al. [12] incorporated five types of work accidents into the output-oriented CCR model to evaluate the safety performance of construction contractors. Shen et al. [13] used the output-oriented CCR model to evaluate road safety performance in countries and considered mortality rate as an output. Finally, Egilmez and McAvoy [14] incorporated fatality rates into the output-oriented Malmquist productivity index approach (based on the CCR model) to evaluate the road safety performance of U.S. states. In addition to the CCR model, other well-known DEA models include the Banker-Charnes-Cooper (BCC) and Slack-Based Measure (SBM) models. These two models are assumed to have inefficient inputs or outputs, which are proportionally adjusted. The SBM model is a non-radial model that can simultaneously incorporate the inefficiencies that result from slack inputs and outputs [15]. The SBM model also has greater discriminating power and the ability to address undesirable outputs [16–18]. Thus, for our purpose, the SBM model is more suitable than the CCR and BCC models.

Previous studies have considered that workers affect the safety performance of firms in different industries [19–21], and the severity of workplace injuries may vary across industries. For example, Tan et al. [22] found a higher rate of deaths in the mining industry than most other industries due to the hazardous nature of the working conditions. Retzer et al. [23] and Witter et al. [21] showed that the oil and gas extraction industry has the highest job fatality rate of all industries. Similarly, Harper and Koehn [24], Idrees et al. [25], and Larsson and Field [26] found a higher rate of workplace injury in the construction industry than in most other industries due to unsafe working conditions. As a proxy for workplace injury, this paper uses occupational injury insurance payment rates, which reflect the assessment of workplace injury incidence. Under work-related injury insurance, an employee who has suffered a work-related wound or illness, disability, or death is entitled to economic compensation. Injuries due to work-related accidents have different levels of severity. As a result, there is a growing need for governments and firms to better manage the three workplace injury rates—wound or illness, disability, and death—and identify targets for improvement.

This paper assesses the safety performance of 17 industrial sectors in Taiwan, and it has the following two objectives: First, it develops an approach that incorporates the three workplace injury rates into the SBM model to evaluate the safety performance of Taiwan's 17 industrial sectors. Second, it discusses methods for improving the implementation of safety strategies for inefficient industrial sectors. The framework can help firms and governments respond quickly and provide improved safety strategies and regulations for each separate industry.

2. Literature Overview

2.1. Safety Performance

Workplace injuries can be regarded as a proxy for firms' safety performance [22]. Previous researchers have shown that over 80% of accidents result from unsatisfactory management [22,27,28]. Accidents may develop from a sequence of deficiencies involving poor safety management and poor comprehensive management systems [22,29,30]. Workplace injuries can also contribute to employee stress and job dissatisfaction and further increase turnover rates [31–33]. Employee turnover leads to the loss of valuable knowledge and skills that employees have developed throughout their experience and training, and to the loss of organizational memory, which negatively affects a firm's productivity and business performance [4–7]. Thus, workplace injuries are unwelcome byproducts of economic activity [12,22]. Researchers have begun to consider workplace injury rates as unwelcome (undesirable) outputs in assessing the safety performance of business operations in a single sector or industry (e.g., [11–14]). This paper assumes that the three workplace injury rates are undesirable outputs.

A number of studies on workplace injuries use econometric models to investigate the factors affecting safety performance (e.g., [1,22,34–37]). In addition, some studies focus on the prevention of errors in business operations that can reduce safety risks for hospital workers [38], airline workers [39], and highway traffic workers [40], among others. The econometric model presents production functions. The estimated expected values are not employed to further assess the safety performance of the DMU, nor does the model provide improved strategies for inefficient DMUs.

2.2. Data Envelopment Analysis

DEA has been widely used as a method for assessing the safety performance of business operations. It generally assumes that more desirable outputs for fewer inputs improves efficiency. Recently, scholars have begun to work on the desirable outputs of economic productions and the occurrence of undesirable outputs [41,42]. Undesirable outputs have received considerable attention in the ecological and environmental literature (e.g., [16,18,43–48]). Undesirable outputs require consideration in sustainable development policy objectives (e.g., [42,49]). They also appear in many other areas, such as health care (complications of medical operations) [41].

The CCR and BCC models assume either an input or an output orientation. The use of a non-oriented SBM model can simultaneously measure the total input and total output of the slack variables [50,51]. In addition, this model is a remarkable alternative largely due to its ability to address undesirable outputs [16]. Incorporating workplace injury into the non-oriented SBM model to measure safety performance can, thus, provide three alternatives for safety strategy decision-making: (1) maximizing desirable outputs and maintaining workplace injury or inputs at the current level; (2) minimizing workplace injuries or inputs and maintaining desirable outputs at the current level; and (3) increasing desirable outputs and decreasing workplace injuries or inputs simultaneously. Therefore, the non-oriented SBM model is recognized as the basic model for measuring the safety performance of business operations. Through slack variable analyses, this model can measure the difference between the goals and objectives of management strategies [42]. Therefore, a non-oriented SBM model is used in this paper to obtain a strong complementary solution.

3. Research Method

The three workplace injury rates are treated as undesirable outputs in the model. This paper assumes that there are n DMUs to be evaluated. Each DMU$_j$ (j = 1, . . . , n) has m inputs x_{ij} (i = 1, . . . , m) and produces p desirable outputs y^d_{rj} (r = 1, . . . , p) and q undesirable outputs of workplace injury rates y^u_{kj} (k = 1, . . . , q, $q = 3$). Therefore, the non-oriented overall efficiency ρ is defined by:

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

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{i0} \qquad i = 1, \ldots, m \tag{1.1}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^d - s_r^d = y_{r0}^d \quad r = 1, \ldots, p \tag{1.2}$$

$$\sum_{j=1}^{n} \lambda_j y_{kj}^u + s_k^u = y_{k0}^u \qquad k = 1, \ldots, q \tag{1.3}$$

$$\lambda \geq 0, s^- \geq 0, s^d \geq 0, s^u \geq 0 \tag{1.4}$$

where s_{i}^- is the slack in the i-th input, s_r^d is the slack in the r-th desirable output, and s_k^u is the slack in the k-th undesirable output. In this model, $0 < \rho^* \leq 1$, and $s^* = 0$ and $\rho^* = 1$ are representative of a given DMU$_0$ with SBM efficiency. Using the optimal slacks $\left(\mathrm{s}_{\mathrm{i}}^{-*},\ \mathrm{s}_{\mathrm{r}}^{d*},\ s_k^{u*}\right)$ in Equation (1), the SBM score ρ^* can be decomposed as follows:

$$\rho^* = \frac{1 - \sum_{i=1}^{m} \alpha_i}{1 + \sum_{r=1}^{p} \beta_r^d + \sum_{k=1}^{q} \beta_k^u} \tag{2}$$

where:

$$\alpha_i = \frac{1}{m}\frac{s_i^{-*}}{x_{i0}} \tag{2.1}$$

$$\beta_r^d = \frac{1}{p+q}\frac{s_r^{d*}}{y_{r0}^d} \tag{2.2}$$

$$\beta_k^u = \frac{1}{p+q}\frac{s_k^{u*}}{y_{k0}^u} \tag{2.3}$$

This is useful for estimating the sources and magnitudes of inefficient industrial sectors relating to the respective inputs—desirable outputs and undesirable outputs—of workplace injury rates for a given DMU_0.

Data Sources and Variables

The process of economic output may generate occupational injuries [23]. Economic output and occupational injuries are intimately related [23,52]. Scholars agree that economic variables should be included in a measure of the safety performance [12,53]. Gross production value (y^d) represents actual economic results at the field level. Previous studies have considered the gross production value (y^g) as the industrial output (e.g., [54–57]). This paper uses the outputs of gross production value (y^d) and the three workplace injury rates (being wounded or ill (y_1^u), disability (y_2^u), and death (y_3^u)).

The economic output of course requires the input of economic resources. Previous studies have suggested that the consumption of fixed capital (x_1) (e.g., [58–61]) can be considered as the input of economic resources because it represents the investment in the value of the fixed capital used in the process of economic output. In addition, employees are the main input in economic activity [62–64]. The data that concern employees include the employee turnover rate (x_2) and their working time. Higher turnover rates tend to correlate with higher accident rates because they often reflect more new hires on the job [65,66], and new hires are more likely to experience workplace accidents [65–67]. Conversely, a lower turnover rate reflects a higher proportion of older employees, who tend to have more experience and knowledge about safety and how to safely work in their specific environment [68]. Thus, employee turnover (x_2) negatively affects the safety performance of business operations [67,69]. Pursuant to the regulations of Taiwan's Labor Standards Act, the regular working time cannot exceed 8 h a day or 84 h every two weeks. Overtime work can lead to greater fatigue, which can undermine employees' safety awareness. Studies have shown that employees who work overtime (x_3) face a greater risk of workplace injury [70–74]. This paper uses the inputs of the consumption of fixed capital (x_1), the employee turnover rate (x_2), and overtime work (x_3).

This paper assesses the safety performance of major industrial sectors in Taiwan in 2015. According to the Standard Industrial Classification, this paper defines 17 industrial sectors: mining and quarrying; manufacturing; electricity and gas supply; water supply and remediation activities; construction; wholesale and retail trade; transportation and storage; accommodation and food services; information and communication; finance and insurance; real estate and residential service; professional, scientific and technical services; support service activities; education; human health and social work services; arts, entertainment and recreation; and other services.

The variables—such as the industry-specific and annual data in the consumption of fixed capital and, more generally, employee turnover rates (x_2), overtime work (x_3), and the gross production value (y^d)—were gathered from the Statistics Committee of Directorate General of Budget, Accounting and Statistics, Executive Yuan of Taiwan [75]. The three workplace injury rates (being wounded or ill (y_1^u), disability (y_2^u) and death (y_3^u)) were collected from the official statistics of the Ministry of Labor [76]. Table 1 provides a description of the variables used in our empirical model.

Table 1. Description of input and output variables, based on incorporating workplace injury into business operational efficiency.

Category	ID	Variables (Unit)
Inputs	x_1	Consumption of fixed capital (NT$ millions)
	x_2	Employee turnover (%)
	x_3	Overtime work (hours/month)
Desirable outputs	y^d	Gross production value (NT$ millions)
Undesirable outputs	y_1^u	Wounded or illness rate (%)
	y_2^u	Disability rate (%)
	y_3^u	Death rate (%)

4. Results and Discussion

Data on the three workplace injury rates (undesirable outputs) and other variables for the 17 industrial sectors are compiled in Table 2. The table shows that it is particularly dangerous for Taiwanese workers to work in other services, construction, and water supply and remediation activities, where the workplace injury rates are, 2.8687, 2.0795, and 1.5270, respectively, all exceeding the national average of 0.8875. Other services (2.6545%) has the highest rate of being wounded or ill, followed by construction (1.9599%) and water supply and remediation activities (1.3976%); and electricity and gas supply (0.0973%) has the lowest injury and illness rate. Mining and quarrying (0.4359%) has the highest rate of disability, followed by other services (0.1841%) and water supply and remediation activities (0.1078%); financial and insurance activities (0.0083%) has the lowest disability rate. Finally, mining and quarrying (0.0769%) has the highest death rate, followed by other services (0.0301%) and construction (0.0230%); human health and social work activities (0.0012%) has the lowest death rate. These findings illustrate that the three workplace injury rates vary significantly between industrial sectors. As injury severity levels vary, this study attempts to improve safety policies in order to decrease the three workplace injury rates in inefficient industrial sectors. The various rates of workplace injuries must be incorporated into the evaluation of safety performance, rather than considering only the sum of the three rates.

This paper investigates the various rates of workplace injuries for safety performance, and the results are summarized in Table 3. This table shows that five industrial sectors with an SBM efficiency score (ρ^*) of 1.0000 (which includes manufacturing, wholesale and retail trade, financial and insurance activities, education and other services), used as a benchmark for the other industrial sectors. The remaining 12 industrial sectors do not perform efficiently. Mining and quarrying has a very low SBM efficiency score (ρ^*) of 0.0490. The industrial sectors achieved an average efficiency score of 0.4272 in 2015. These results indicate that Taiwan's industrial sectors continue to have room to improve their safety performance in this business operations environment.

Inefficient industrial sectors that require improvement in safety performance are determined through slack variable analysis (see Table 4). As can be seen, all of the gross production values were satisfactory. The average gross production value of each industrial sector increased gradually over the 2010–2015 period. This implies that the economic output of the industrial sector has been given considerable attention. Mining and quarrying (0.0008) has the greatest difference between the disability rate and the death rate. Taiwan's Labor Safety and Health Act requires that employers provide workers with at least six hours of training and that workers pass a health and safety test before working. However, the six hours of training may not be sufficient to increase employees' health and safety knowledge to the point of reducing dangerous actions or to enable them to identify hazards. In addition, increasing safety investment in the number and quality of professional personnel and management personnel could contribute to reducing severe injuries and death in the mining industry [22]. Construction (0.0166) has the greatest difference between the rates of injury and illness. Idrees et al. [25] proposed that mental stress should be considered in the workplace for the health and safety of construction workers. Taiwan's construction industry has a very high incidence of illnesses and injuries [67,77–79]; possible reasons include (1) the inherently hazardous nature of construction projects; (2) personnel factors; (3) environmental and equipment factors; (4) project factors; and (5) management factors [69,78,79]. To reduce the rate of illnesses and injuries in the construction industry, it is important to implement required health and safety practices and provide effective training to ensure that all employees follow these requirements when working [79–81]. Electricity and gas supply should reduce the amount of overtime work performed by employees. These industrial sectors should adopt precautionary measures, such as adjusting the amount of overtime and averaging workloads to improve safety performance. Moreover, the difference in the employee turnover rate for accommodation and food service is 8.5203. This sector has the highest employee turnover rate in Taiwan and has often struggled to attract quality talent because of its relatively low wages. The low wages are often attributed to the part-time or seasonal nature of the work. Management in this industry should provide workers with improved wages and more stable working conditions. In addition, Ho and Kuo [82] suggested that employees should show a degree of caution when working with a new team member and not trust their firm's ability to ensure that new employees work safely and have the relevant contextual knowledge. These suggestions are important when choosing appropriate safety management practices and implementing them effectively.

Table 5 shows the primary sources and magnitudes of inefficient industrial sectors using decompositions. The primary sources and magnitudes of most inefficient industrial sectors are overtime work and death caused by excess. Davies et al. [83] observed that both minor and major injuries are related to working overtime. Indeed, overtime work can lead to greater fatigue, which can undermine employees' safety awareness and health. This information may increase the Taiwanese government's understanding of the improvements required for each industrial sector and enable it to make subsequent improvements.

Sensitivity analysis can examine the stability of efficiency scores by omitting an efficient industrial sector and consequently, changing a reference set for the industrial sector. Table 6 shows the results of evaluating industrial sectors using sensitivity analysis. A group of efficient industrial sectors (i.e., wholesale and retail trade, financial and insurance activities, and other services) considerably influence the magnitudes of the efficiency scores estimates of other inefficient industrial sectors at the level that some inefficient industrial sectors may become efficient if the industrial sector belonging to the group is omitted. The other group of efficient industrial sectors (i.e., manufacturing and education) do not have such a major influence on the inefficient industrial sectors.

Table 2. Data on the three workplace injury rates and other variables.

DMUs	Consumption of Fixed Capital (x_1)	Employee Turnover (x_2)	Overtime Work (x_3)	Gross Production Value (y^d)	Wounded or Illness Rate (y_1^u)	Disability Rate (y_2^u)	Death Rate (y_3^u)	Total Workplace Injury Rate
Mining and quarrying	3310	2.09	4.2	16,597	0.6667%	0.4359%	0.0769%	1.1795%
Manufacturing	1,205,751	3.83	15.3	5,005,978	0.5964%	0.0530%	0.0061%	0.6555%
Electricity and gas supply	117,806	1.34	9.7	307,752	0.0973%	0.0168%	0.0101%	0.1242%
Water supply and remediation activities	15,796	3.25	4.8	102,261	1.3976%	0.1078%	0.0216%	1.5270%
Construction	20,719	5.18	5	420,136	1.9599%	0.0966%	0.0230%	2.0795%
Wholesale and retail trade	141,206	4.61	3.2	2,727,033	0.5293%	0.0281%	0.0051%	0.5624%
Transportation and storage	105,351	3.99	9.4	509,109	1.0472%	0.0574%	0.0183%	1.1229%
Accommodation and food service activities	30,354	9.24	3.1	425,746	1.0343%	0.0298%	0.0062%	1.0702%
Information and communication	105,808	4.04	2.5	486,629	0.2259%	0.0092%	0.0031%	0.2382%
Financial and insurance activities	104,902	2.78	2.6	1,093,299	0.1485%	0.0083%	0.0016%	0.1583%
Real estate activities	181,077	5.67	2.5	1,359,816	0.4746%	0.0137%	0.0034%	0.4917%
Professional, scientific, and technical activities	45,522	3.66	4.6	346,782	0.3865%	0.0150%	0.0063%	0.4078%
Support service activities	33,800	8.68	9	254,600	0.6693%	0.0281%	0.0126%	0.7100%
Education	56,142	4.13	0.6	700,549	0.6919%	0.0328%	0.0082%	0.7329%
Human health and social work activities	44,337	2.81	4.2	493,952	0.3704%	0.0111%	0.0012%	0.3826%
Arts, entertainment, and recreation	12,002	7.9	2.1	144,922	0.7454%	0.0216%	0.0090%	0.7760%
Other services	10,360	3.83	2.7	430,436	2.6545%	0.1841%	0.0301%	2.8687%
Average	131,426.0588	4.5312	5.0294	872,093.9412	0.8056%	0.0676%	0.0143%	0.8875%
Standard Deviation	273,355.7757	2.1517	3.6233	1,205,305.5587	0.6676%	0.1055%	0.0181%	0.7217%

Table 3. Incorporating the three workplace injury rates into the SBM model to evaluate efficiency scores and rankings among industries.

DMUs	SBM Efficiency Score (æ*)	Rank
Mining and quarrying	0.0490	17
Manufacturing	1.0000	1
Electricity and gas supply	0.1378	13
Water supply and remediation activities	0.0922	16
Construction	0.3122	7
Wholesale and retail trade	1.0000	1
Transportation and storage	0.1208	14
Accommodation and food service activities	0.2233	9
Information and communication	0.1731	10
Financial and insurance activities	1.0000	1
Real estate activities	0.4587	6
Professional, scientific, and technical activities	0.1516	12
Support service activities	0.1075	15
Education	1.0000	1
Human health and social work activities	0.2693	8
Arts, entertainment, and recreation	0.1664	11
Other services	1.0000	1
Average	0.4272	
Standard deviation	0.3925	

Table 4. The differences for each output and input variable.

DMUs	Input Excess (s^-)			Desirable Output Shortfall (s^d)	Undesirable Output Excess (s^u)		
	Consumption of Fixed Capital (x_1)	Employee Turnover (x_2)	Overtime Work (x_3)	Gross Production Value (y^d)	Wounded or Illness rate (y_1^u)	Disability Rate (y_2^u)	Death Rate (y_3^u)
Mining and quarrying	2910.5331	1.9423	4.0959	0.0000	0.0056	0.0043	0.0008
Electricity and gas supply	101,870.5753	0.8198	9.3389	0.0000	0.0004	0.0001	0.0001
Water supply and remediation activities	10,500.9167	3.0771	4.6800	0.0000	0.0138	0.0011	0.0002
Construction	0.0000	4.2004	4.3164	0.0000	0.0166	0.0008	0.0002
Transportation and storage	78,989.2928	3.1294	8.8026	0.0000	0.0095	0.0005	0.0002
Accommodation and food service activities	8308.8360	8.5203	2.6004	0.0000	0.0095	0.0003	0.0001
Information and communication	80,610.3091	3.2174	1.9290	0.0000	0.0013	0.0000	0.0000
Real estate activities	105,012.2550	3.2622	0.7502	0.0000	0.0022	0.0000	0.0000
Professional, scientific, and technical activities	27,565.5986	3.0738	4.1931	0.0000	0.0032	0.0001	0.0001
Support service activities	20,616.7904	8.2496	8.7012	0.0000	0.0062	0.0003	0.0001
Human health and social work activities	18,760.1236	1.9750	3.6204	0.0000	0.0027	0.0001	0.0000
Arts, entertainment, and recreation	4497.9266	7.6550	1.9299	0.0000	0.0072	0.0002	0.0001

Table 5. The inefficiency decomposition for each output and input variable.

DMUs	The Decomposition of Input Inefficiency (ff_i)			The Decomposition of Desirable Output Inefficiency (fi^d)	The Decomposition of Undesirable Output Inefficiency (fi^u)		
	Consumption of Fixed Capital (x_1)	Employee Turnover (x_2)	Overtime Work (x_3)	Gross Production Value (y^d)	Wounded or Illness Rate (y_1^u)	Disability Rate (y_2^u)	Death Rate (y_3^u)
Mining and quarrying	0.2931	0.3098	0.3251	0.0000	0.2822	0.3279	0.3283
Electricity and gas supply	0.2882	0.2039	0.3209	0.0000	0.1288	0.2704	0.3144
Water supply and remediation activities	0.2216	0.3156	0.3250	0.0000	0.3286	0.3301	0.3304
Construction	0.0000	0.2703	0.2878	0.0000	0.2815	0.2646	0.2852
Transportation and storage	0.2499	0.2614	0.3121	0.0000	0.3019	0.3029	0.3162
Accommodation and food service activities	0.0912	0.3074	0.2796	0.0000	0.3067	0.2842	0.2906
Information and communication	0.2540	0.2655	0.2572	0.0000	0.1940	0.1517	0.2352
Real estate activities	0.1933	0.1918	0.1000	0.0000	0.1532	0.0000	0.0000
Professional, scientific, and technical activities	0.2018	0.2799	0.3038	0.0000	0.2753	0.2540	0.2994
Support service activities	0.2033	0.3168	0.3223	0.0000	0.3087	0.3022	0.3208
Human health and social work activities	0.1410	0.2343	0.2873	0.0000	0.2471	0.1800	0.0000
Arts, entertainment, and recreation	0.1249	0.3230	0.3063	0.0000	0.3208	0.3103	0.3234

Table 6. Results of the sensitivity analysis.

Inefficient DMUs	Efficient DMUs				
	Manufacturing	Wholesale and Retail Trade	Financial and Insurance Activities	Education	Other Services
Mining and quarrying	0.0490	0.0490	0.0490	0.0490	0.0617
Electricity and gas supply	0.1378	0.2149	0.1378	0.1378	0.1378
Water supply and remediation activities	0.0922	0.1458	0.0922	0.0922	0.0922
Construction	0.3122	1.0000	0.3122	0.3122	1.0000
Transportation and storage	0.1208	0.2078	0.1208	0.1208	0.1208
Accommodation and food service activities	0.2233	1.0000	0.2233	0.2233	0.2233
Information and communication	0.1731	0.2998	0.1731	0.1731	0.1731
Real estate activities	0.4587	1.0000	1.0000	0.4587	0.4587
Professional, scientific, and technical activities	0.1516	0.2670	0.1516	0.1516	0.1516
Support service activities	0.1075	0.1954	0.1075	0.1075	0.1075
Human health and social work activities	0.2693	1.0000	0.2693	0.2693	0.2693
Arts, entertainment, and recreation	0.1664	0.2733	0.1664	0.1664	0.1664

5. Conclusions

Workplace injuries are an undesirable output within business operations and economic activities. A number of studies of workplace injuries have used different econometric models to investigate the factors that affect safety performance. It is difficult for these studies to provide comprehensive policies for improving safety performance for policymakers. An efficient safety policy is required to reduce workplace injury. To design such policy, policymakers must select an optimal set of measures. Therefore, we developed the DEA-SBM model, which incorporates three workplace injury rates (being wounded or ill, disability, and death) to evaluate the safety performance of 17 industrial sectors in Taiwan. This paper revealed that mining and quarrying has lower levels of safety performance than the other industrial sectors. Additionally, the paper used slack variable analysis provided by the Taiwanese government for improving safety performance based on the specific contexts of each industry. Using inefficiency decompositions, this paper found that the primary sources and magnitudes of most inefficient industrial sectors are overtime work and death rates caused by excess. Based on this finding, government policies can give priority to addressing these two issues.

Future researchers may consider using the dynamic DEA model to measure changes in efficiency scores over time and to further explore the effects of common factors (such as business cycles) on the safety performance of business operations. Asfaw et al. [84] demonstrated that the incidence of workplace injuries varies with economic fluctuation.

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