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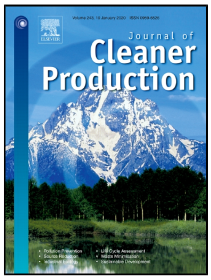

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Assessing the carry-over effects of both human capital and organizational forgetting on sustainability performance using dynamic data envelopment analysis

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Abstract

Many studies have documented that human capital, which is a result of professional knowledge accumulation, continuously improves sustainability performance over time. Organizational forgetting is the loss of such professional knowledge, and it results in lower sustainability performance. Thus, human capital and organizational forgetting can be respectively treated as good and bad carry-overs. Both human capital and organizational forgetting may reflect business cycle fluctuations. The data envelopment analysis model has not been employed to examine the impact of either human capital or organizational forgetting on sustainability performance in multi-stages. The aim of this study is to develop a three-stage approach to incorporate the carry-over effects of both human capital and organizational forgetting and the effects of business cycle fluctuations on overall and term sustainability performance using data from Taiwan's 16 major industrial sectors. The study finds that the carry-over effects of human capital and organizational forgetting lead to accurate estimations of sustainability performance and illustrates that the development of the industrial economy is a critical factor for adjusting human capital. Governments should implement economic stabilization policies and increase investment in education and safe capital to improve human capital accumulation and enhance sustainability performance.

Keywords: sustainability performance; dynamic data envelopment analysis; human capital; occupational injury; organizational forgetting

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1 Introduction

It is increasingly important that both firms and countries aiming to develop the industrial economy in a healthy and safe manner assess their sustainable performance, as the process of economic growth may generate bad outputs, such as occupational injuries (Kang et al., 2018; Tan et al., 2012). In addition to bad outputs such as occupational injuries, human capital also plays a key role in the development of a sustainable economy (Chang et al., 2013a; Hatch and Dyer, 2004; Jabbour et al., 2019; Labuschagne et al., 2005). Human capital is the stock of professional and safety knowledge accumulated through continuous learning from work experience and helps firms both increase economic growth and avoid occupational injuries (Cooper et al., 2016; Hitt et al., 2001; Lei et al., 2013; Michael et al., 2006; Phusavat et al., 2011). Hence, the stock of human capital reflects cumulative results over a number of previous periods and is regarded as an important factor in assessing sustainability performance (Haugland et al., 2007). Human capital maintains and increases its intangible value when organizations hire, develop, and retain the best employees (Azapagic, 2004; Chang et al., 2013a; Shaw et al., 2013). However, firms cannot directly own this intangible human capital because human capital manifests itself as employee expertise and knowledge (Labuschagne et al., 2005).

Organizational forgetting refers to the hypothesis that a firm's human capital stock depreciates over time (Kogan et al., 2017). If forgetting is present, it may represent that loss of the previous stock of human capital (prior knowledge) (Benkard, 2000). The depreciation of human capital might be related to employee turnover, and it contributes to the loss of valuable employee knowledge, which in turn negatively affects sustainability performance (Dess and Shaw, 2001; Hancock et al., 2013; Kogan et al., 2017).

Because intangible capability is a cumulative result, it necessarily involves carry-over activities between time periods (Yeh et al., 2016). As noted above, the current stock of human capital and organizational forgetting are cumulative because they are the result of carry-overs from previous experience. Thus, human capital and organizational forgetting can be treated as good carry-overs and bad carry-overs. Gibbons and Waldman (2004) found that human capital is specific to the nature of the work within an industrial sector not specific to a firm. The different levels of injury severity can be influenced by the differences in industrial working environments, where workers are exposed to different hazards (Ruser, 2014; Viscusi, 2004; Witter et al., 2014; Yeh, 2017). Dangerous working environments lead to increased turnover rates (Benjamin and Matthias, 2004; Dawson and Surpin, 2001; Tiyce et al., 2013), and higher turnover rates suggest that knowledge is forgotten in a short time (Tsang and Zahra, 2008). Industrial sectors vary in the extent to which their knowledge depreciates and the degree of organizational

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forgetting (Benkard, 2000). Human capital and organizational forgetting may reflect past levels of economic activity, and thus sustainability performance and the business cycle are intimately related (Kalemli-Ozcan et al., 2000).

Prior studies have used learning and organizational forgetting experience curves to examine human capital and organizational forgetting and their impact on sustainability performance (e.g., Badiru, 1995; Badiru and Ijaduola, 2009; Cooper and Johri, 2002). Badiru and Ijaduola (2009) showed how the learning and organizational forgetting experience curve has been widely applied in various fields. However, the expected value of a parameter as estimated by learning and organizational forgetting experience curves has not been used to measure sustainability performance or to provide effective strategies to improve occupational injuries, resource allocation or economic growth in inefficient industrial sectors. In particular, sustainability performance tends to be a nonlinear, dynamic process with multiple inputs and/or multiple outputs. Hence, these studies are not used to assess the sustainability performance of industrial sectors or to improve human capital and organizational forgetting by creating a strategy to promote a safe and motivating environment in inefficient industrial sectors (Hatch and Dyer, 2004; Hitt et al., 2001; Shou et al., 2018; Tamayo-Torres et al., 2016). Ahn and Chang (2004) showed that policymakers can effectively manage their human capital and create a safe and motivating environment to generate and maintain a sustainable competitive advantage.

Two mathematical methods are the most commonly used to evaluate performance. One approach is stochastic frontier analysis, which uses a parametric technique to assess various production and cost frontiers. However, organizational memory / forgetting are generally complex learning activities with multiple inputs and outputs (Guan et al., 2006) that potentially have nonlinear relationships (Guan and Zuo, 2014; Guan et al., 2016). In addition, the parametric approach requires a predetermined specific production function (Guan et al., 2006). The other method is data envelopment analysis (DEA), which applies a nonparametric technique to trace the efficiency frontier (Chang et al., 2013a) that does not need to specify a specific production function (Chang et al., 2013b; Guan et al., 2016; Lyu et al., 2018). In addition, DEA can simultaneously handle multiple inputs and outputs expressed in different units of measurement (Yeh et al., 2016). Traditional DEA models focus on separate time periods and treat each period as independent of the others without considering carry-over activities between two consecutive time periods. Thus, Tone and Tsutsui (2010) developed the dynamic slack-based measure (SBM) model, which enables us to measure period-specific performance based on long-term optimization throughout the period. The advantage of dynamic SBM is that it uses cumulative intangible capital as a carry-over, as it is difficult to ascribe a monetary value to such capital. For instance, Yeh et al. (2016) suggested that in evaluating recycling performance, the learning effect is considered to be a carry-over effect. However, organizational forgetting is also a relatively important factor in assessing the performance of business operations. Several studies have ignored the carry-over effects of organizational forgetting on

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sustainability performance (Badiru and Ijaduola, 2009; Chang et al., 2013b). Dynamic SBM has certain advantages over mathematical models in evaluating the sustainability performance of industrial sectors because it incorporates the carry-over effects of both human capital and organizational forgetting. Hence, this study integrates learning and organizational forgetting experience curves with dynamic SBM, aiming to improve sustainability performance.

Business cycle fluctuations affect human capital and organizational forgetting (Cooper and Johri, 2002; Kalemli-Ozcan et al., 2000; Martin and Rogers, 2000; Topel, 1999), and these two intangible attributes have carry-over effects on the sustainability performance of industrial sectors. There is a gap in the literature concerning how to integrate the carry-over effects of both human capital and organizational forgetting and the effects of business cycle fluctuations into sustainability performance measures. Thus, existing methodologies are insufficient for investigating this relationship and discussing the methods for formulating improved sustainability performance for inefficient industrial sectors.

The contribution of this study is fourfold: (1) this study develops an approach that incorporates the carry-over effects of both human capital and organizational forgetting into a dynamic SBM model that evaluates the sustainability performance of industrial sectors; (2) this study applies this approach to assess the sustainability performance of 16 industrial sectors in Taiwan; (3) this study explores the association between the business cycle and intertemporal sustainability performance trends; and (4) this study provides evidence showing the effects of the business cycle on the relative adjustment of industrial sectors' human capital and organizational forgetting.

2 Conceptual model and hypotheses

The production of good outputs (y^g), such as economic outputs, requires the input of economic resources (x). Meanwhile, the process of economic growth may generate bad outputs (y^b), such as occupational injuries (Chan and Chan, 2011; Kang et al., 2018; Tan et al., 2012). The traditional DEA model uses economic resources (x) as inputs, economic outputs (y^g) as good outputs and occupational injuries (y^b) as a bad outputs when estimating the sustainability performance of industrial sectors, as shown in Fig. 1. This traditional model assumes that production technologies are independent across time periods.

[Insert Fig. 1 here]

However, current human capital ($\widehat{c_t^g}$) is also the main input of future economic outputs (y_{t+1}^g) (Bano et al., 2018; Haugland et al., 2007), since more experienced employees have more human capital and should have more knowledge about safety and about how to work safely in their industry-specific environment (Michael et al., 2006; Nishimura and Okamuro, 2011; Shaw et al., 2013). Thus, current

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human capital inputs ($\widehat{c_t^g}$) can prevent future occupational injuries (y_{t+1}^b) (Michael et al., 2006; Sheu et al., 2000). The current accumulated stock of human capital ($\widehat{c_t^g}$) enables industries to increase their future economic outputs (y_{t+1}^g) and reduce their future occupational injuries (y_{t+1}^b), resulting in an improvement in future sustainability performance. The current accumulated stock of human capital ($\widehat{c_t^g}$) tends to generate strong incentives and create more opportunities for further investment in human capital formation ($\widehat{c_{t+1}^g}$). In contrast, organizational forgetting ($\widehat{c^b}$) in industries can lead to a reduction in future good outputs (y_{t+1}^g), increase future occupational injuries (y_{t+1}^b), and result in decreased future sustainability performance (Becker, 2009; Dess and Shaw, 2001; Hancock et al., 2013). Human capital ($\widehat{c^g}$) and organizational forgetting ($\widehat{c^b}$) are considered good carry-overs and bad carry-overs, respectively. The results of incorporating the carry-over effects of both human capital ($\widehat{c_t^g}$) and organizational forgetting ($\widehat{c^b}$) on sustainability performance are presented in Fig. 2. The DEA framework proposed measures the difference rates between the inefficiency of an industrial sector and the benchmark for each period, thereby providing dynamic adjustment strategies in inefficient industrial sectors.

[Insert Fig. 2 here]

Business cycle fluctuations could have an impact on organizational forgetting ($\widehat{c^b}$), as an economic downturn leads to a reduction in economic activities (Seles et al., 2019), which in turn slows the pace of work and reduces occupational accidents (y^b). Chang et al. (2018) observed that experienced workers are more likely to turn over because they seek jobs with higher wages and better working conditions during periods of economic upturn. Asfaw et al. (2011) noted that workers may not receive adequate training on safety issues, may overlook safety rules and may not properly satisfy safety requirements when the pace of work increases under a growing economy. In addition, being injured on the job may contribute to employee stress and discontent and ultimately increase turnover rates (Yamada, 2002). A higher turnover rate often means more opportunity to recruit new employees (Choi et al., 2012; El-Mashaleh et al., 2010), but these inexperienced employees are more subject to occupational accidents (y^b) (Choi et al., 2012; El-Mashaleh et al., 2010; Hinze, 1978). Thus, employee turnover leads to the loss of experienced workers and further contributes to the loss of organizational memory (Hatch and Dyer, 2004; McCaughey et al., 2013). Economic growth leads to an increase in occupational injuries (y^b) and further leads organizations to quickly forget knowledge (Chang et al., 2018). This loss of knowledge in these industrial sectors can bring a decline in sustainability performance when industrial sectors have high organizational forgetting ($\widehat{c^b}$). Therefore, organizational forgetting negatively affects sustainability

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performance. For these reasons, among inefficient industrial sectors, a reduction in organizational forgetting ($\widehat{c^b}$) is recommended.

Hypothesis 1: The business cycle is negatively correlated with the inefficient adjustment of organizational forgetting.

Economic recessions are periods of foregone learning opportunities, so adverse business cycle shocks have a negative impact on human capital accumulation ($\widehat{c^g}$) (Martin and Rogers, 2000). Economic growth could have a positive impact on human capital accumulation ($\widehat{c^g}$) because in a growing economy, employees have more opportunities to learn by doing (Kalemli-Ozcan et al., 2000; Martin and Rogers, 2000). Countries with higher levels of industrial economic development may also have a greater need to retain experienced employees (Retzer et al., 2013; Shou et al., 2018; Tamayo-Torres et al., 2016), and these experienced employees should have more knowledge of safety and of how to safely work in their specific environments (Michael et al., 2006; Nishimura and Okamuro, 2011). Industrial sectors with high human capital ($\widehat{c^g}$) tend to utilize resources more efficiently and are likely to benefit from professional knowledge to maintain sustainable economic development. Increased human capital ($\widehat{c^g}$) may thus result in better sustainability performance, and it could be recommended that an inefficient industrial sector increase human capital ($\widehat{c^g}$).

Hypothesis 2: The business cycle is positively correlated with the inefficient adjustment of human capital.

Because human capital ($\widehat{c^g}$) and organizational forgetting ($\widehat{c^b}$) may reflect past levels of economic activity (Cooper and Johri, 2002; Kalemli-Ozcan et al., 2000), sustainability performance and the business cycle are intimately related. Economic growth not only helps industrial sectors increase human capital accumulation ($\widehat{c^g}$) but also leads to an increase in organizational forgetting ($\widehat{c^b}$). However, human capital ($\widehat{c^g}$) and organizational forgetting ($\widehat{c^b}$) are distinct economic forces that are not only affected by the business cycle but also have an impact on economic activities. A favorable business cycle shock has a positive effect on profit growth (y^g) (Seles et al., 2019). Thus, the business cycle may affect human capital ($\widehat{c^g}$), organizational forgetting ($\widehat{c^b}$) and profitability (y^g), thereby impacting sustainability performance.

Hypothesis 3: The business cycle is positively correlated with sustainability performance.

3 Method and data sources

The dynamic SBM model is generally assumed to be based on a set of observed attributes. Human capital ($\widehat{c^g}$) and organizational forgetting ($\widehat{c^b}$) are unobservable attributes, and they are reflected in cumulative results over long periods. This study uses a three-stage methodology.

1. For each period, human capital $(\widehat{c_t^g})$ and organizational forgetting $(\widehat{c_t^b})$ are estimated for each industrial sector.
2. The human capital $(\widehat{c_t^g})$ and organizational forgetting $(\widehat{c_t^b})$ for each period are integrated into a dynamic SBM model.
3. Regression models are used to investigate the effects of the business cycle on the second-stage dynamic DEA results. The intertemporal sustainability performance trends and the relative adjustment of human capital $(\widehat{c^g})$ and organizational forgetting $(\widehat{c^b})$ are included.

   The detailed processes are summarized in equations as follows:

3.1 Human capital and organizational forgetting until term T is estimated for each industrial sector

Human capital can be accumulated through past work experience, which can typically be measured by cumulative output value $(\sum_{s=0}^{s=t} ex_s)$ (Hatch and Dyer, 2004). Labor hours $(Cost_t)$ will follow an experience-shaped curve that decreases as the cumulative output value $(\sum_{s=0}^{s=t} ex_s)$ increases. Because a firm's experience is embodied in its employees, it is likely that turnover will lead to a loss of experience. Thus, the loss of experience can be measured by cumulative turnover $(\sum_{s=0}^{s=t} tur_s)$. The learning and forgetting experience curves have been the most widely used model because they generally provide a good fit to the observations (Badiru and Ijaduola, 2009; Nembhard, 2000). These experience curves are thus specified as follows:

$$Cost_t = \alpha \times \frac{1}{\left(\sum_{s=0}^{s=t} ex_s\right)^{\beta_1}} \times \left(\sum_{s=0}^{s=t} tur_s\right)^{\beta_2} \qquad (1)$$

where $Cost_t$ equals the work hours in period *t*, α denotes a constant parameter, $\sum_{s=0}^{s=t} ex_s$ measures the cumulative output value of industry at time *t*, $\sum_{s=0}^{s=t} tur_s$ measures the cumulative turnover rates at time *t*, β_1 is the experience coefficient, and β_2 is the forgetting coefficient. By taking the natural logarithm of both sides of Equation (1) and adding an error term at time *t* (ε_t), the following estimable form of the learning and forgetting experience curves is obtained:

$$lnCost_t = ln\alpha - \beta_1\, ln\sum_{s=0}^{s=t} ex_s + \beta_2\, ln\sum_{s=0}^{s=t} tur_s + \varepsilon_t \qquad (2)$$

The long time-series data can be used to obtain estimates of the experience coefficient $\widehat{\beta_1}$ and the forgetting coefficient $\widehat{\beta_2}$ using Equation (2). These estimates can be applied to obtain measures of human capital for every period ($\widehat{c_t^g}$), $\left(\sum_{s=0}^{s=t} ex_s\right)^{\widehat{\beta_1}}$; organizational forgetting for every period ($\widehat{c_t^b}$) is $\left(\sum_{s=0}^{s=t} tur_s\right)^{\widehat{\beta_2}}$.

3.2 Estimated human capital and organizational forgetting are integrated into the dynamic DEA model

Consider the dynamic process presented in Fig. 2 that addresses n industrial sectors (j = 1, …, n) over T terms (t = 1…, T). These estimated period values of human capital and organizational forgetting are confirmed as a good carry-over, $\widehat{c_{jt}^g}$, and a bad carry-over, $\widehat{c_{jt}^b}$. Each industrial sector also has m common inputs x_{ijt} (i = 1, …, m), R_1 good outputs y_{rjt}^g (r = 1, …, R_1), and a bad output of occupational injuries and accidents y_{jt}^b. Using these expressions for the dynamic process, this study expresses the observed industrial sector$_o$ and defines overall efficiency θ by solving the following:

$$\text{Minimize } \theta_0^* = \frac{1}{T}\sum_{t=1}^{T}\left[\frac{1-\frac{1}{m+1}\left(\sum_{i=1}^{m}\frac{s_{it}^-}{x_{i0t}}+\frac{s_t^{bad}}{\widehat{c_{0t}^b}}\right)}{1+\frac{1}{R_1+2}\left(\sum_{r=1}^{R_1}\frac{s_{rt}^{+g}}{y_{r0t}^g}+\frac{s_t^{+b}}{y_{0t}^b}+\frac{s_t^{good}}{\widehat{c_{0t}^g}}\right)}\right] \qquad (3)$$

subject to

$$x_{i0t} = \sum_{j=1}^{n} x_{ijt}\lambda_j^t + s_{it}^- \qquad (i = 1,\dots,m) \qquad (3.1)$$

$$y_{r0t}^g = \sum_{j=1}^{n} y_{rjt}^g\lambda_j^t - s_{rt}^{+g} \qquad (r = 1,\dots,R_1) \qquad (3.2)$$

$$y_{0t}^b = \sum_{j=1}^{n} y_{jt}^b\lambda_j^t + s_t^{+b} \qquad (3.3)$$

$$\widehat{c_{0t}^g} = \sum_{j=1}^{n} \widehat{c_{jt}^g}\lambda_j^t - s_t^{good} \qquad (3.4)$$

$$\widehat{c_{0t}^b} = \sum_{j=1}^{n} \widehat{c_{jt}^b}\lambda_j^t + s_t^{bad} \qquad (3.5)$$

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$$\sum_{j=1}^{n} \widehat{c_{jt}^{g}}\lambda_j^t = \sum_{j=1}^{n} \widehat{c_{jt}^{g}}\lambda_j^{t+1} \quad (3.6)$$

$$\sum_{j=1}^{n} \widehat{c_{jt}^{b}}\lambda_j^t = \sum_{j=1}^{n} \widehat{c_{jt}^{b}}\lambda_j^{t+1} \quad (3.7)$$

$$\sum_{j=1}^{n} \lambda_j^t = 1 \quad (3.8)$$

$\lambda_j^t \geq 0, s_{it}^- \geq 0, s_{rt}^{+g} \geq 0, s_t^{+b} \geq 0, s_t^{good} \geq 0, s_t^{bad} \geq 0$

where s_{it}^-, s_{rt}^{+g}, s_t^{+b}, s_t^{good} and s_t^{bad} are slack factors denoting excess input, good output shortfall, bad output of occupational injuries and accident excess, the carry-over effect of human capital shortfall and the carry-over effect of excess organizational forgetting. Using an optimal solution ($\{s_{it}^{-*}\}$,$\{s_{rt}^{+g*}\}$, $\{s_t^{+b*}\}$,$\{s_t^{g*}\}$,$\{s_t^{b*}\}$) in Equation (3), the efficiency for term *t* is deconstructed as follows:

$$\theta_{0t}^* = \frac{1 - \frac{1}{m+1}\left(\sum_{i=1}^{m} \frac{s_{it}^{-*}}{x_{i0t}} + \frac{s_t^{b*}}{\widehat{c_{0t}^{b}}}\right)}{1 + \frac{1}{R_1+2}\left(\sum_{r=1}^{R_1} \frac{s_{rt}^{+g*}}{y_{r0t}^{g}} + \frac{s_t^{+b*}}{y_{0t}^{b}} + \frac{s_t^{g*}}{\widehat{c_{0t}^{g}}}\right)} \quad (4)$$

This study defines the overall efficiency score θ_0^* and the term efficiency score θ_{0t}^* as ratios that range between 0 and 1; they are 1 when all slacks are zero. Table 1 summarizes the dataset and important DEA results for evaluating the sustainability performance of Taiwan's major industrial sectors. In the proposed model of this study, some of the important results are an evaluation of the efficiency scores of each industrial sector and an analysis of inefficient industrial sectors.

[Insert Table 1 near here]

3.3 Using regression models to explain the relationship between the business cycle and the DEA results

In the third step, this study utilizes the term efficiency score θ_{0t}^* and the difference rates (adjustment of each inefficient industrial sector's original data) for each period generated from the second-stage DEA methodology and uses these values as the dependent factors to identify the business cycle, which affects efficiency trends and their factor adjustment processes. Because the efficiency scores and the adjustment of each inefficient DMU's original data for each period lie between 0 and 1, using ordinary least squares regression may lead to estimated parameters that are inconsistent and biased. Cooper et al. (2007) suggested that the Tobit regression model is more appropriate for examining whether exogenous factors affect the efficiency score and the difference rates. To be more explicit about this test, consider the following Tobit regression specification:

$$DV_{jt}^* = \beta_3 BC_{jt} + \varepsilon_t \quad (5)$$

where DV_{jt} is the dependent factor (the term efficiency score and the difference rates) in term *t*, and BC_{jt} equals the business cycle in term *t*.

3.4 Data sources

In terms of carry-overs, annual work hours $Cost_t$, annual total industrial output value ex_s and annual turnover rates tur_t can be used to obtain the estimated period values of human capital $\widehat{c_t^g}$ and organizational forgetting $\widehat{c_t^b}$ using Equation (2). Gross production value (NT$ millions) y^g represents the actual economic results and is considered a good industrial output (Yeh, 2017). Occupational injury rates (per 1,000 employees) (%) y^b can be considered a bad output in terms of sustainability performance. The consumption of fixed capital (NT$ millions) x can be considered an input because it represents the investment in fixed capital during the economic processes of producing good output y^g (Boussemart et al., 2011; Yeh et al., 2016). The industrial production index is commonly used as a business cycle indicator (Asfaw et al., 2011).

This study assesses sustainability performance using data from Taiwan's 16 major industrial sectors. In accordance with the Standard Industrial Classification, Taiwan's major 16 industrial sectors were defined as follows: Mining and Quarrying; Manufacturing; Electricity and Gas Supply; Water Supply; Construction; Wholesale and Retail Trade; Transportation and Storage; Accommodation and Food Services; Information and Communication; Finance and Insurance; Real Estate and Residential Services; Professional, Scientific and Technical Services; Support Service Activities; Human Health and Social Work Services; Arts, Entertainment and Recreation; and Other Services. Data on the estimated period values of human capital $\widehat{c_t^g}$ and organizational forgetting $\widehat{c_t^b}$ for the period of 1981-2015 are provided, and the other inputs and outputs and the industrial production index are provided for 2010-2015. The annual occupational injury rates y^b were collected from the official statistics of the Ministry of Labor (http://statdb.mol.gov.tw/statis/), and the other variables were taken from Directorate-General of Budget, Accounting and Statistics, Executive Yuan of Taiwan (http://ebas1.ebas.gov.tw). These two databases have been used extensively in academic research (e.g., Chang et al., 2018; Yang et al., 2018; Yeh, 2017).

4 Results

In the first stage, for each period, human capital and organizational forgetting are estimated for each industrial sector. Table 2 provides descriptive statistics regarding estimated human capital and organizational forgetting and compiles the inputs and outputs used for the 2010-2015 period.

[Table 2 near here]

In the second stage, this study incorporates these estimated values of human capital and organizational forgetting and other factors into sustainability performance measurements. This study first

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compares the term efficiency scores derived using the proposed methodology and those obtained using the traditional DEA model (see Fig. 1) to examine the accuracy of the proposed DEA methodology. The traditional model does not explain the carry-over effects of both human capital and organizational forgetting. For ease of comparison, the traditional DEA model uses static SBM instead of other static modes, as the static SBM model can deal with inputs and outputs individually and hence allows for their nonproportional changes. Thus, the static SBM model has been found to have a greater ability to address bad output compared to other static models. Table 3 summarizes the average efficiency scores of 16 industrial sectors from 2010 to 2015. The standard deviations under the traditional DEA model are generally lower than those under the proposed DEA methodology. This finding suggests that when the carry-over effects of both human capital and organizational forgetting are considered, the differences in sustainability performance between industrial sectors become more apparent. The most critical ingredients of a firm's resource endowment are not tangible capital but intangible capital (Chu et al., 2006; Wong and Wong, 2014). Intangible capital includes different unique features that influence to the firm's core competency. If firms can increase their intangible capital stock, their uniqueness will be enhanced (Yeh et al., 2016). The average efficiency scores obtained using the traditional model are consistently lower than those obtained using the proposed DEA methodology. This study next uses the nonparametric statistical Wilcoxon signed-rank test to examine whether these observed differences are statistically significant. The empirical evidence indicates that integrating the carry-over effects of both human capital and organizational forgetting into the sustainability performance measurement yields a significant difference. This result suggests that considering the carry-over effects of both human capital and organizational forgetting could lead to more accurate sustainability performance of Taiwan's industrial sectors. These findings further support the use of the proposed DEA methodology.

[Insert Table 3 here]

The evaluated overall and term efficiency scores of the 16 industrial sectors are presented in Table 4, which shows that 6 of the 16 industrial sectors are overall efficient. The remaining ten industrial sectors do not perform efficiently in any term. Mining and Quarrying had its lowest overall efficiency score at 0.1114, and its term efficiency scores decreased gradually over the study period. The results imply that the sustainability performance of Mining and Quarrying has a slight deteriorating trend. This study finds that the average efficiency score of each industrial sector is approximately 0.6440-0.6555 over the 2010-2015 period. The industrial sectors achieve an average efficiency score of 0.6474 over the 2010-2015 sample period with respect to overall efficiency. These results show that Taiwan's 16 major industrial sectors continue to have considerable room to improve their overall sustainability performance in this dynamic business environment.

[Insert Table 4 here]

Table 5 details the room for improvement and possible change trends for the inputs, outputs and carry-overs of inefficient industrial sectors. The results presented in this table support the safety management of business operations, providing a direction for business deployment and creating a practical concept that follows that direction. A higher value for the difference rates indicates that the impact generated from the variable is stronger. The findings show that the Support Service Activities sector has the highest proportion of difference rates in the consumption of fixed capital and human capital during each term. Firms in the Support Service Activities sector must move to knowledge-based services, in which human capital plays a key role. When firms have higher levels of human capital, they tend to be more efficient in utilizing knowledge and resources (Variyam and Kraybill, 1993). The results also indicate that inefficiency in Mining and Quarrying has the highest proportion of difference rates in that sector's occupational injury rates, organizational forgetting and gross production values during each term; they further show that organizational forgetting has expanded gradually over the period. In general, occupational injuries can harm a company's reputation, decrease economic growth (Sheu et al., 2000), and result in employee turnover and a further loss of organizational memory. The occurrence of occupational injuries can reflect insufficient investment in infrastructure or poor management (Cagno et al., 2014; Hymel et al., 2011; Tan et al., 2012). Tan et al. (2012) argue that increasing safety capital inputs could contribute to reducing occupational injuries, resulting in economic growth in the mining industry. Firms in this industry do not adequately invest in training, and workers' technical and vocational skills should be strengthened (Azapagic, 2004; Wu, 2010). There are many industries for which inefficiency is primarily a result of insufficient gross production value and insufficient human capital. Shaw et al. (2013) believe that when human capital accumulation is high, an organization is likely to profit from organization-specific skills, knowledge, and abilities to sustain industrial development and economic growth.

[Insert Table 5 here]

In the third stage, this study further examines how the business cycle affected the DEA results using a regression analysis. Table 5 presents the regression results for these 6-year observations. The table shows that the business cycle has a significantly negative effect on the mean adjustment of organizational forgetting; it also has significantly positive impacts on the mean adjustment of human capital and mean intertemporal sustainability performance at a significance level of 1%. These results indicate that the signs of the coefficients are consistent with the hypotheses. The coefficient results indicate a change in business cycle fluctuations given a percent change in the dependent factors. The factor with the largest effect is the percent change in the adjustment of human capital. The results showed that business cycle shocks have the largest positive impact on human capital accumulation. Economic growth and stable development lead to more learning opportunities and further help industrial sectors increase their human capital accumulation. Thus, the government's willingness and ability to implement economic stabilization policies could have a positive impact on human capital accumulation and, through this capital accumulation, economic growth. When organizations have higher levels of human capital, they tend to be more efficient in utilizing skills, knowledge and resources and more likely to profit from organization-specific skills, knowledge, and the ability to maintain sustainable economic development. Motivating workers to work more safely is likely to increase the stock of human capital, thus reducing occupational injuries and increasing economic growth (Langford et al., 2000; Tseng et al., 2015).

[Insert Table 6 here]

Continual learning has been one of the key driving forces of sustainable economic development (Kaur et al., 2019; Oliva et al., 2019; Singh et al., 2019c). Government investment in education and healthcare is likely to increase the stock of human capital and thus increase economic growth (Justesen, 2008). A firm invested in training its workers is rationally developing human resource management strategies that help to retain these employees and motivate and develop them to best utilize their skills and knowledge, and it will thereby increase economic growth (Singh et al., 2019a). This study argues that increasing safety-related training and education inputs is a necessary step to counter the effect of the business cycle on the sustainability performance of industrial sectors during economic expansion. This finding implies that the sustainability performance of industrial sectors suffers whenever there is a slowdown in the economy and regardless of the government's management ability or efforts.

5 Discussion

This study developed a methodology that integrates the carry-over effects of both human capital and organizational forgetting with the effects of business cycle fluctuations on the sustainability performance of industrial sectors. Because many business operations strategies involve intangible capital and substantial dynamics (Singh et al., 2019b), this methodology can provide additional insights into the dynamic sustainability performance of industrial sectors' activities.

The DEA model proposed evaluates and ranks the sustainability performance of Taiwan's 16 industrial sectors. The empirical results integrate the carry-over effects of both human capital and organizational forgetting into the sustainability performance assessment, effectively reducing the problem of underestimating and enhancing the differences between industrial sectors. The result also provides an efficiency ranking of different industrial sectors, wherein the Mining and Quarrying sector has lower sustainability performance and an intertemporal trend of gradually decreasing sustainability performance. Policymakers should be aware that there is still room for improvement in the sustainability performance in Taiwan's industrial sectors. Thus, this study performs a slack variable analysis to examine the improvement directions and trend for each inefficient industry; its findings should help firms and the Taiwanese government establishes a strategy to improve safety performance.

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Policymakers need to be aware that business cycle fluctuations have significantly positive impacts on the sustainability performance of industrial sectors. Sustainability performance may prove hard to increase despite policymakers' efforts if there is a slowdown in the economy or a recession. The Taiwanese government implements economic growth and stabilization policies to promote the sustainability performance of industrial sectors. In particular, human capital and organizational forgetting are distinct economic forces with differential impacts on sustainability performance. Business cycle fluctuations have a strong effect on adjusting human capital. The performance of these policies is subjected to the Taiwanese government's capabilities, and a willingness to implement economic growth-oriented policies could have the largest positive impact through human capital accumulation on improving sustainability performance.

6 Conclusions

Economic growth helps industrial sectors accumulate human capital, leading to an increase in occupational injuries and organizational forgetting. The cumulative stocks of human capital and organizational forgetting have both positive and negative impacts on the sustainability performance of industrial sectors, and this relationship is difficult to investigate using a traditional approach.

This study makes several contributions: (1) it developed a methodology that integrates the carry-over effects of both human capital and organizational forgetting with the effects of business cycle fluctuations and looks at their impact on the sustainability performance of industrial sectors; (2) it assessed the sustainability performance of Taiwan's 16 industrial sectors, providing a more accurate measure of sustainability performance and increasing the ability to discriminate among industrial sectors. This study found that Taiwan's industrial sectors show a gradually decreasing intertemporal sustainability performance trend over the study period, especially in the Mining and Quarrying industries. (3) This study also explores the association between the business cycle and intertemporal sustainability performance trends. The regression analysis demonstrates that business cycle fluctuations have a significantly positive impact on intertemporal sustainability performance trends, and (4) the analysis provides evidence of the effects of the business cycle on the relative adjustment of human capital and organizational forgetting among industrial sectors, illustrating that the development of the industrial economy is a key factor in adjusting the stock of human capital. The Taiwanese government's ability and willingness to implement economic stabilization policies and increase investment in education and safety could have a positive impact on human capital accumulation, and through this capital accumulation, economic growth could improve sustainability performance.

This study is limited and provides direction for future study. This study is based on data collected from 16 industrial sectors in Taiwan. Therefore, the findings reflect unique aspects of Taiwan's industrial sectors. Policymakers need to exercise caution when generalizing these study findings to other nations.

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Future study needs to test the proposed methodology in a different country setting. There is a need to examine whether explanatory factors such as safety policy, safety training, and safety equipment are associated with sustainability performance (Asfaw et al., 2011; Kang et al., 2018; Tan et al., 2012). This study explores the impact of these explanatory factors, but more detailed firm information and a larger scope of data collection are necessary. The present study is focused only on sustainable economic development; however, the proposed dynamic DEA method could be explored in the green supply chain management, human capital management and knowledge management fields.

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Conflict of interests

Dear Editor

Greetings

This study is free of Conflict of interests

Regards

Authors

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Author contribution Section

1. Li-Ting Yeh Initiates this work
2. Ming-Lang Tseng is re-write and checking this work
3. Ming K. Lim is finalized this manuscript

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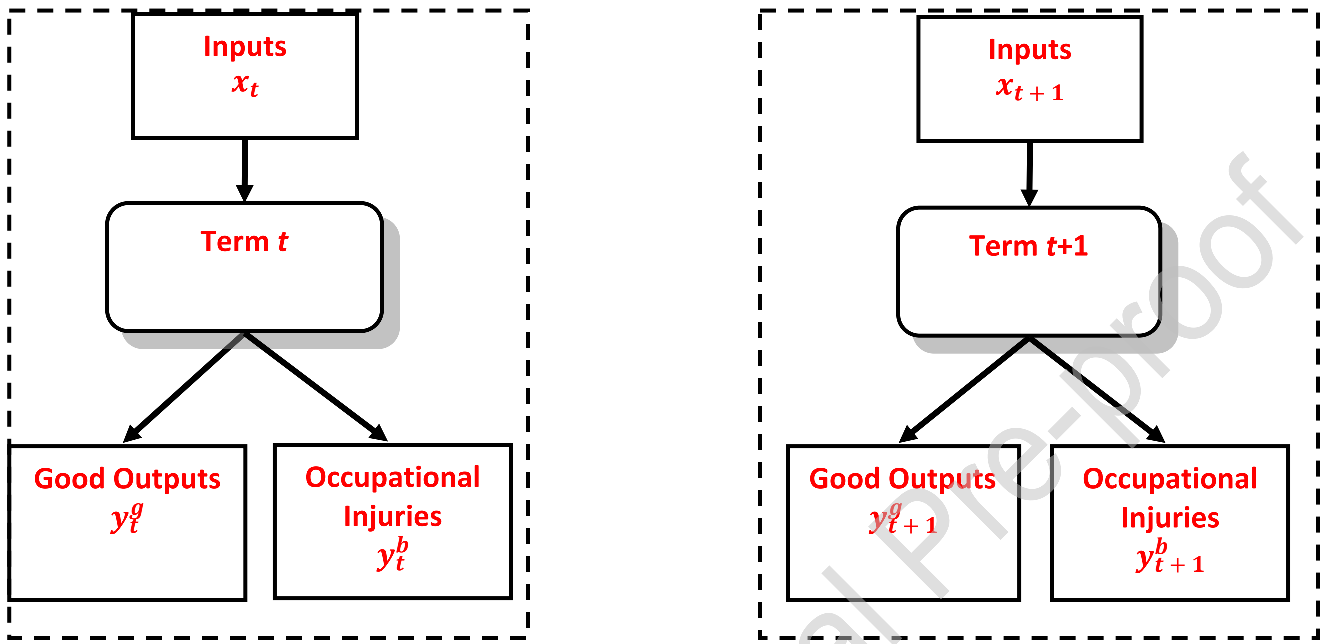

Figure 1. The traditional DEA model does not consider the carry-over effects of either human capital or organizational forgetting.

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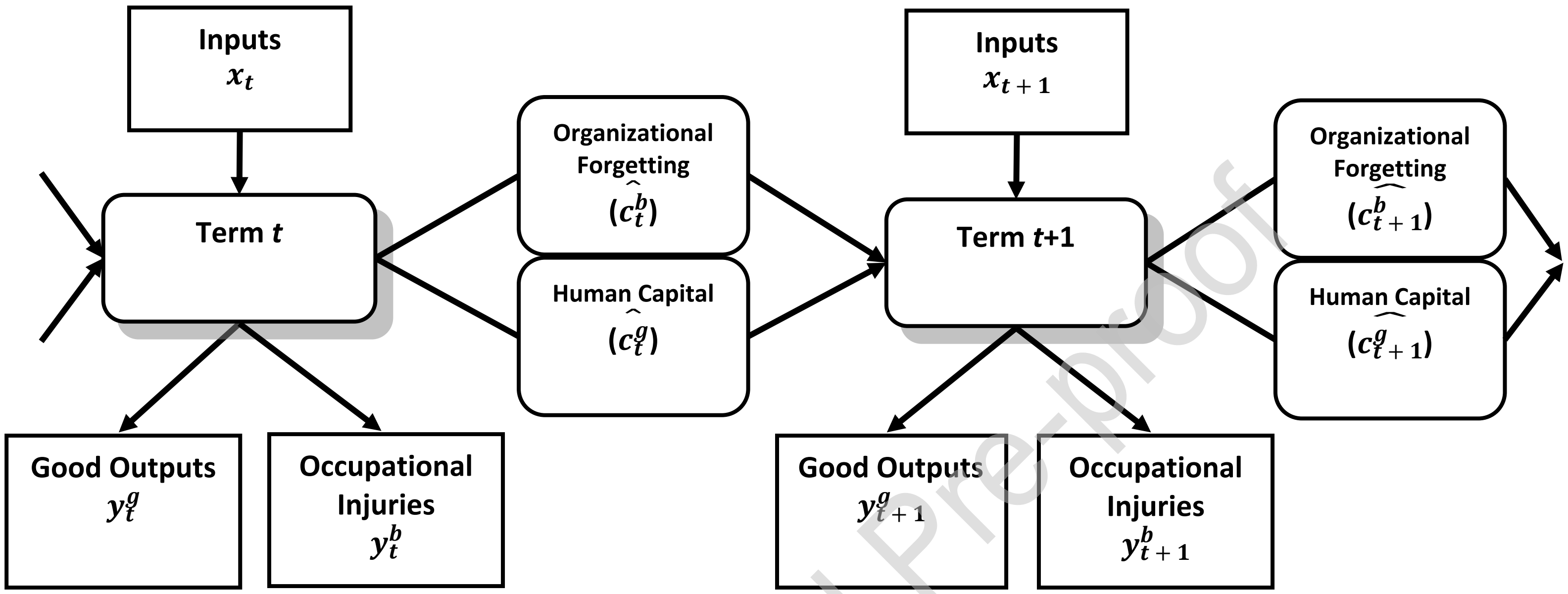

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Figure 2. Incorporating the carry-over effects of both human capital and organizational forgetting on the sustainability performance of industrial sectors.

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Highlights

- The proposed approach incorporates human capital and forgetting into dynamic DEA.
- Human capital and forgetting can lead to changes in sustainable performance.
- Business cycle fluctuations have a significant impact on sustainable performance.
- Development of the industrial economy is crucial to adjusting human capital.

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Tables

Table 1. Dataset and important DEA results.

Dataset		DEA results	
Variables (variable symbol)	Description	Efficiency scores	Analysis of inefficient industrial sectors
Industrial sectors (*j*) ($j = 1, \ldots, n$)	The evaluated organization	Overall efficiency θ_j^* of each industrial sector	Benchmark firms (λ_j^t) of inefficient firm *j* in the *t*th term
Terms (*t*) ($t = 1, \ldots, T$)	Each period	Term efficiency $\theta_{jt}{}^*$ of each industrial sector	Projected differences in consumption of fixed capital in term t $(\frac{s_t^-}{x_{0t}} \times 100\%)$
Input (x)	Consumption of fixed capital		Projected differences in occupational injury rate in term t $(\frac{s_t^{+b}}{y_{0t}^b} \times 100\%)$
Bad output (y^b)	Occupational injury rate		Projected differences in economic output in term t $(\frac{s_t^{+g*}}{y_{0t}^g} \times 100\%)$
Good output (y^g)	Economic output		Projected differences in human capital in term t $(\frac{s_t^{good}}{\hat{c}_{0t}^g} \times 100\%)$
Good carry-over ($\hat{c}^g$)	Human capital		Projected differences in organizational forgetting in term t $(\frac{s_t^{b*}}{\hat{c}_{0t}^b} \times 100\%)$

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Bad carry-over ($\hat{c}^b$)	Organizational forgetting

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Table 2. Descriptive statistics for estimated human capital and organizational forgetting and the collected inputs and outputs (N = 16 industrial sectors).

Term	Category	**Variable**	**Average**	Max	Min	St Dev
2010	Input	Consumption of fixed capital (x)	119,374.69	1,043,332.00	3,698.00	251,116.67
	Bad output	Occupational injury rate (y^b)	3.9457	13.5590	0.2770	3.6632
	Good output	Gross production value (y^g)	734,964.13	4,090,594.00	19,008.00	1,063,787.00
	Good carry-over	Human capital ($\hat{c}^g$)	3.7041	9.6180	0.9460	2.5368
	Bad carry-over	Organizational forgetting ($\hat{c}^b$)	1.2675	1.7818	0.8752	0.2595
2011	Input	Consumption of fixed capital (x)	124,782.06	1,101,020.00	3,707.00	265,130.21
	Bad output	Occupational injury rate (y^b)	3.6472	13.4750	0.3000	3.3619
	Good output	Gross production value (y^g)	744,877.56	4,102,225.00	17,174.00	1,075,451.39
	Good carry-over	Human capital ($\hat{c}^g$)	3.6949	9.6239	0.8978	2.4597
	Bad carry-over	Organizational forgetting ($\hat{c}^b$)	1.2696	1.7867	0.8573	0.2541
2012	Input	Consumption of fixed capital (x)	129,036.38	1,147,402.00	3,520.00	276,385.25
	Bad output	Occupational injury rate (y^b)	3.7668	13.3630	0.2780	3.4970
	Good output	Gross production value (y^g)	756,425.06	4,120,882.00	15,500.00	1,078,398.93
	Good carry-over	Human capital ($\hat{c}^g$)	3.6210	9.4165	0.8569	2.3696
	Bad carry-over	Organizational forgetting ($\hat{c}^b$)	1.2654	1.7813	0.8415	0.2501
2013	Input	Consumption of fixed capital (x)	128,553.69	1,137,998.00	3,402.00	274,068.00
	Bad output	Occupational injury rate (y^b)	3.5616	12.5730	0.2280	3.3302
	Good output	Gross production value (y^g)	794,633.63	4,360,226.00	15,471.00	1,138,005.79
	Good carry-over	Human capital ($\hat{c}^g$)	3.5970	9.4352	0.8581	2.3151
	Bad carry-over	Organizational forgetting ($\hat{c}^b$)	1.2660	1.7892	0.8410	0.2468
2014	Input	Consumption of fixed capital (x)	134,026.44	1,189,192.00	3,434.00	286,416.94
	Bad output	Occupational injury rate (y^b)	3.2798	12.0150	0.2150	2.9414
	Good output	Gross production value (y^g)	848,412.25	4,833,196.00	16,766.00	1,241,533.26
	Good carry-over	Human capital ($\hat{c}^g$)	3.5491	9.4118	0.8521	2.2510
	Bad carry-over	Organizational forgetting ($\hat{c}^b$)	1.2638	1.7943	0.8377	0.2433
2015	Input	Consumption of fixed capital (x)	136,131.31	1,205,751.00	3,310.00	290,318.85
	Bad output	Occupational injury rate (y^b)	3.0796	11.1070	0.2290	2.7998
	Good output	Gross production value (y^g)	882,815.50	5,005,978.00	16,597.00	1,282,333.25
	Good carry-over	Human capital ($\hat{c}^g$)	3.5882	9.4796	0.8666	2.2459

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Bad carry-over	Organizational forgetting ($\hat{c}^b$)	1.2714	1.8036	0.8422	0.2422

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Table 3. Term efficiency scores from the two-stage DEA methodology and the traditional DEA model.

Model	The two-stage DEA methodology: Integrating the carry-over effects of both human capital and organizational forgetting				The traditional DEA model: Not integrating the carry-over effects of both human capital and organizational forgetting				Wilcoxon signed rank test z-stat
Term	Average	Max	Min	St Dev	Average	Max	Min	St Dev	
2010	0.6439	1	0.1253	0.3180	0.4326	1	0.0818	0.3128	2.7735***
2011	0.6472	1	0.1170	0.3178	0.4281	1	0.0704	0.3159	2.7735***
2012	0.6444	1	0.1058	0.3172	0.4255	1	0.0621	0.3161	2.7735***
2013	0.6501	1	0.1050	0.3151	0.4278	1	0.0650	0.3146	3.3282***
2014	0.6455	1	0.1099	0.3152	0.4256	1	0.0688	0.3123	3.3282***
2015	0.6553	1	0.1085	0.3122	0.4379	1	0.0677	0.3093	3.3282***
Total	0.6477	1	0.1050	0.3075	0.4296	1	0.0621	0.3052	8.0392***

Note: *** Statistical significance at the 1% level.

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Table 4. Overall and term efficiency scores of 16 industrial sectors.

	Efficiency score							
DMUs	Overall	2010	2011	2012	2013	2014	2015	Rank
Mining and Quarrying	0.1114	0.1253	0.1170	0.1058	0.1050	0.1099	0.1085	16
Manufacturing	1	1	1	1	1	1	1	1
Electricity and Gas Supply	1	1	1	1	1	1	1	1
Water Supply	0.2332	0.2198	0.2275	0.2342	0.2434	0.2384	0.2381	15
Construction	0.4305	0.4089	0.4215	0.4231	0.4396	0.4438	0.4490	12
Wholesale and Retail Trade	1	1	1	1	1	1	1	1
Transportation and Storage	1	1	1	1	1	1	1	1
Accommodation and Food Services	0.5878	0.5504	0.5919	0.5950	0.6053	0.5929	0.5956	9
Information and Communication	0.5096	0.5206	0.5247	0.5053	0.4987	0.4808	0.5282	11
Finance and Insurance	1	1	1	1	1	1	1	1
Real Estate and Residential Service	0.6318	0.6692	0.6968	0.6162	0.6383	0.5772	0.5941	8
Professional, Scientific and Technical Services	0.5120	0.4948	0.4949	0.5205	0.5104	0.5086	0.5449	10
Support Service Activities	0.2560	0.2660	0.2553	0.2501	0.2553	0.2555	0.2541	14
Human Health and Social Work Services	0.6604	0.6521	0.6292	0.6399	0.6730	0.6675	0.7044	7
Arts, Entertainment and Recreation	0.4262	0.3952	0.3970	0.4205	0.4329	0.4530	0.4684	13
Other Services	1	1	1	1	1	1	1	1
Average	0.6474	0.6439	0.6472	0.6444	0.6501	0.6455	0.6553	

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Table 5. Inefficiency difference rates from the proposed two-stage DEA methodology.

Term	2010	2011	2012	2013	2014	2015
Excess (s_t^-) (%)-Consumption of fixed capital (x)						
Mining and Quarrying	-27.2500	-28.0700	-24.8600	-24.6400	-24.8500	-23.2700
Water Supply	-52.1900	-55.1200	-56.4100	-55.7500	-56.6900	-58.0700
Construction	-39.0300	-36.3400	-37.8400	-36.5000	-36.3400	-35.8200
Accommodation and Food Services	0.0000	-0.2600	-4.1700	-8.6600	-12.8500	-18.2000
Information and Communication	-12.4900	-13.8200	-12.3100	-6.5300	-4.3000	-0.8400
Real Estate and Residential Services	-43.2400	-34.9000	-46.1000	-46.5700	-46.8700	-45.6200
Professional, Scientific and Technical Services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Support Service Activities	-72.9500	-75.5600	-78.2600	-79.5400	-80.9400	-79.9300
Human Health and Social Work Services	0.0000	0.0000	-0.1800	0.0000	0.0000	0.0000
Arts, Entertainment and Recreation	-1.2700	-1.9200	0.0000	-2.2200	-1.4800	-32.7800
Average	-15.5263	-15.3744	-16.2581	-16.2756	-16.5200	-18.4081
Excess (s_t^{+b}) (%)-Occupational injury rates (y^b)						
Mining and Quarrying	-94.1800	-91.2900	-93.7600	-93.0100	-89.9100	-90.6100
Water Supply	-77.7200	-77.4700	-77.2700	-72.3700	-71.5000	-72.1400
Construction	-86.2600	-86.1600	-86.4100	-84.4000	-84.0900	-83.8400
Accommodation and Food Services	-49.6200	-48.0200	-49.1000	-45.1100	-46.9400	-47.2800
Information and Communication	-51.7400	-40.3500	-48.7000	-53.4600	-56.1200	-32.6400
Real Estate and Residential Services	-1.8300	0.0000	-18.9400	-8.2000	-31.1100	-25.0000
Professional, Scientific and Technical Services	-10.1600	-5.0400	-0.0700	0.0000	0.0000	0.0000

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Support Service Activities	-45.4600	-48.7500	-49.1000	-46.7900	-45.1200	-47.0200
Human Health and Social Work Services	-62.7000	-57.8800	-56.3500	-53.9800	-57.1600	-50.8800
Arts, Entertainment and Recreation	-49.2100	-49.3900	-39.4700	-34.2400	-22.3200	-28.2400
Average	-33.0550	-31.5219	-32.4481	-30.7225	-31.5169	-29.8531
Shortage (s_t^{+g}) (%)-Gross production value (y^g)						
Mining and Quarrying	380.4100	441.3600	519.0700	533.2300	519.5000	535.7500
Water Supply	152.0200	150.1400	147.9500	154.2900	165.8300	169.1200
Construction	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Accommodation and Food Services	92.0000	75.6200	68.5500	63.3500	61.3900	52.7200
Information and Communication	87.3200	98.1800	101.9300	108.0700	120.4800	124.7000
Real Estate and Residential Services	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Professional, Scientific and Technical Services	136.1200	143.9500	133.5800	140.3800	140.7200	117.3300
Support Service Activities	5.0700	2.9600	0.2400	0.0000	0.0000	0.0000
Human Health and Social Work Services	4.8800	18.1500	16.3400	8.4200	7.4100	1.2000
Arts, Entertainment and Recreation	188.0900	187.2400	185.5300	180.6800	183.6400	118.1200
Average	65.3694	69.8500	73.3244	74.2762	74.9356	69.9338
Shortage (s_t^{good}) (%)-Human capital ($\widehat{c^{good}}$)						
Mining and Quarrying	37.2300	25.7400	18.1000	10.8500	5.4900	0.0000
Water Supply	163.8900	127.6700	104.1200	90.7900	86.8300	72.8300
Construction	84.8500	79.0400	73.6700	66.3300	63.7600	61.1900
Accommodation and Food Services	4.7400	0.0000	1.2100	2.0600	3.9100	5.8800
Information and Communication	14.6300	13.8300	12.4800	11.5000	9.7000	9.9400
Real Estate and Residential Services	52.7700	52.5800	53.0800	55.6100	55.9900	57.3900
Professional, Scientific and Technical	1.3300	0.0800	0.0400	0.0000	1.3600	2.1900

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Services						
Support Service Activities	245.3300	253.5600	259.9400	251.6200	252.5000	252.9900
Human Health and Social Work Services	1.9400	1.2200	0.7300	0.5300	0.0000	1.6300
Arts, Entertainment and Recreation	12.3600	8.1100	5.3000	2.1900	0.0000	0.0600
Average	38.6919	35.1144	33.0419	30.7175	29.9712	29.0062
Excess (s_t^{bad})-Organizational forgetting ($\widehat{c^{bad}}$)						
Mining and Quarrying	-62.4900	-63.6100	-64.3900	-65.1600	-65.7500	-66.3800
Water Supply	0.0000	-4.3400	-7.4700	-9.3900	-9.9500	-11.9400
Construction	0.0000	-1.0700	-2.0800	-3.4800	-3.9800	-4.4300
Accommodation and Food Services	-5.4100	-7.0200	-5.9900	-5.2400	-4.2500	-3.4700
Information and Communication	0.0000	-0.2600	-0.6500	-0.9300	-1.4400	-1.3900
Real Estate and Residential Services	-1.1900	-1.1100	-1.0100	-0.4800	-0.4100	0.0000
Professional, Scientific and Technical Services	-39.3900	-39.5700	-39.4800	-39.4100	-39.0200	-38.8200
Support Service Activities	-1.8800	-0.8500	0.0000	-0.7200	-0.4900	-0.3900
Human Health and Social Work Services	-35.0100	-35.0700	-35.1100	-35.0800	-35.1500	-34.7900
Arts, Entertainment and Recreation	-12.1100	-13.2500	-14.0200	-14.8900	-15.5100	-15.4500
Average	-9.8425	-10.384	-10.638	-10.924	-10.997	-11.066

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Table 6. Regression results.

Dependent variables	**Coefficient**	**z-Statistic**	**Std. Error**
Inter-temporal sustainability performance	0.000064	73.23252***	0.000001
Adjustment of organizational forgetting ($\widehat{c^b}$)	-0.001051	-120.7322***	0.000009
Adjustment of human capital ($\widehat{c^g}$)	0.003220	18.17006***	0.000177

Note: *** Statistical significance at the 1% level.

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