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Economic, Social, Medical, Work Injury, and Environmental Efficiency Assessments

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Abstract

Improving the management efficiency of industrial accidents is significant for stabilizing social order and improving production efficiency. Although many previous studies have discussed the impact of work injury on different occupations from the work safety and health perspectives, few have jointly discussed economic, social, medical, and environmental pollution issues, and those that do mostly employ static models, failing to take into account welfare factors and environmental pollution issues that affect society. Therefore, in order to understand the dynamic evolution trend between social and economic activities and environmental issues, this study utilizes a modified undesirable two-stage dynamic exogenous data envelopment analysis (DEA) model to explore the economic, social, medical, and environmental efficiencies of 30 provinces in China to fill the gap in the literature. In terms of work injury insurance expenditure efficiency, the results show that the air quality index (AQI) impacts the ranking of China's 30 provincial regions, with Fujian, Ningxia, Qinghai, Shandong, Tianjin, and Xinjiang being greatly affected. AQI significantly influences overall factor efficiency, rescue invalid deaths, and the work-related injuries in the various regions. AQI also has a relatively small effect on the efficiency of work injury insurance benefits. Based on this, we offer suggestions for policy makers to evaluate the social benefits of environmental governance and the efficiency of human capital.

Keywords

medical treatment, industrial injury, air pollution, environmental efficiency, two-stage dynamic exogenous DEA model

What we already know about this topic?

China was 120th among 180 countries, as its air quality index (AQI) ranked fourth from last among all countries. The 2018 China Environmental Bulletin shows that 75.1% of cities in China exceed the ambient air quality standard, and the proportion of cities with acid rain is 19.8%. Sudden air pollution accidents have increased, and the probability of work injuries has also risen in China.

How does your research contribute to the field?

This study offers 3 contributions to the literature. First, this study analyzes the impact of government-invested welfare insurance such as work injury and medical care on professional labor efficiency in order to discuss the efficiency of economic, social, medical, and environmental aspects. Second, we explore the effect on regions' economic and social efficiencies under exogenous environmental conditions. Third, considering dynamic changes, we propose a modified undesirable two-stage dynamic exogenous DEA model to solve for the lack of static analysis.

What are your research's implications toward theory, practice, or policy?

This study found that air pollution will significantly affect the efficiency of medical injuries in various regions of China. This has important policy implications for local policy makers in China to comprehensively evaluate the social benefits of medical injury policies. (1) Policy makers should improve the living environment quality of workers, reduce the negative impact caused by air pollution, and reduce the probability of medical industrial accidents. (2) This study finds that air pollution also has a direct impact on medical insurance expenditures and the number of insurance benefits, and it also has a negative impact on the output of workers. Although the Chinese government has issued a series of policies to control the environment in recent years, it has not fundamentally improved China's environmental pollution. Therefore, policy makers should strive to explore ways to fundamentally improve China's environmental pollution and reduce the negative impact of air pollution on inventors' innovation output. (3) The study found that the impact of air pollution on the efficiency of medical work-related injuries is quite different among provinces in China. We should focus on implementing differentiated energy saving and haze reduction strategies, and establish a market-oriented long-term energy-saving and hegemony reduction mechanism.

Introduction

When gross domestic product (GDP) per capita of developing countries is relatively low, the level of labor productivity is generally not high, and labor utilization is inadequate. Therefore, for many developing countries, economic growth and employment rates are important for government decision-making, yet maintaining rapid economic growth often comes at the cost of the environment. Along with the deepening of industrialization and urbanization in developing countries, industrial pollution has caused severe smog. A World Health Organization report shows that about 90% of the world's population breathe polluted air. In 2016, outdoor air pollution and indoor air pollution caused 4.2 million and nearly 4 million deaths worldwide, respectively.

The heavy chemical industry is the core of China's national economy and has made great contributions to its rapid growth in recent years,[1,2] but at the same time the country has paid a high environmental cost. In 2011, China's carbon emissions accounted for 28% of the world's total. In 2013, China experienced severe smog, spreading to 25 provinces and more than 100 large and medium-sized cities. In the 2018 global environmental performance ranking, China was 120th among 180 countries, as its air quality index (AQI) ranked fourth from last among all countries. The 2018 China Environmental Bulletin shows that 75.1% of cities in China exceed the ambient air quality standard, and the proportion of cities with acid rain is 19.8%. Air pollution in north China is even more severe, bringing great negative impacts to residents' lives and mental health, reducing people's well-being.[3,4] Smog not only can interrupt people's livelihoods, but also impacts the sustainable development of China's economy, which are trends that need urgent change and adjustment.

With the rapid development of China's economy, sudden air pollution accidents have increased, and the probability of work injuries has also risen. In 2016, 1 036 139 workers were identified as work-related injuries and 22 436 workers died at work in China. Environmental pollution accident has become a major environmental problem in the world. Therefore, improving the treatment efficiency of medical accidents is particularly critical for stabilizing social order and improving production efficiency. At present, China is implementing the strategy of "healthy China", and employee safety and health is an indispensable part of the strategy. In order to prevent workers from being harmed by harmful factors and improve their health, China has established a medical insurance system for work-related injuries.

In recent years, the scale and income of industrial injury insurance fund have been expanding. As of October 2017, the income of work-related injury insurance fund has reached 67.4 billion yuan (RMB), with an accumulated balance of 155.8 billion yuan (RMB).[5] Ninety-eight percent of the prefectures and cities have realized the overall planning at the municipal level, 11 provinces have realized the provincial coordination, and 30 provinces have established reserves, and the scale of national reserves has reached 25.5 billion yuan (RMB).[5] However, the situation of occupational health is facing the problem of unbalanced and insufficient development. On the one hand, multiple disease threats coexist and multiple health influencing factors interweave. On the other hand, the development of occupational health work is extremely unbalanced in China's economically developed and underdeveloped areas.

Based on this, our research takes air pollution as an exogenous condition, discusses the impact of it on industrial accidents in 30 provinces of China, and answer the following questions: (1) How much does air pollution affect the efficiency of industrial injury insurance in China? (2) Does air pollution affect the efficiency of industrial injury and the total factors of invalid deaths in different regions of China? (3) The impact of air pollution on the efficiency of medical work-related injuries in different regions of China. And evaluates the efficiencies of all factors of medical work injury in various provinces and regions in order to find the differences in medical treatment in various regions and improve environment pollution control efficiency.

It is a common problem in the world to effectively maintain the safety and health of employees in the process of production and labor. At present, with the rapid development of global industrialization, economic and social development has made great progress. However, industrial accidents also occur frequently. Therefore, the industrial accidents caused by economic and social development have also attracted the attention of many scholars.

Many scholars' research has been carried out from 2 aspects: On the 1 hand, it is a study on the problems of work safety and health injuries. For example, Poplin et al[6] explored the regulatory methods of the mining industry to reduce work-related injuries through annual data on industrial injury rates of bituminous coal in the United States (U.S.) Queensland (QLD), and New South Wales (NSW) in Australia from 1996 to 2004. The results show that health and safety regulations are inversely related to the injury rate. Robinson et al[7] analyzed the economic impact of hand and

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wrist injuries, showing results that these injuries cause a great burden on individuals and society. Heron-Delaney et al[8] discuss health problems and non-work risks of 194 claimants who were injured in traffic accidents. The results present that the level of disability has a significant impact on an individual's successful return to work. Başağa et al[9] discussed the occupational health and safety (OHS) education of workers in Turkey's construction industry and showed results that the overall occupational health and safety of the trained personnel needs to be strengthened. Lette et al[10] used stratified multi-stage sampling to assess the incidence of injury among construction workers in Ethiopia. Their findings presented that the total incidence of work-related injuries is 41.4%, and that working without personal protective equipment (PPE) increases the likelihood of injury to construction workers. Syron et al[11] analyzed the risk of injury in the offshore processing industry from 2010 to 2015. Their results noted that most injuries are musculoskeletal. It is thus necessary to adjust the workload and improve the safety of any working environment in a timely manner. Kwon et al[12] explored the relationship between the fatigue driving risk index and sleep of Korean professional drivers via logistic regression analyses. The results showed that working hours exceeding 12 hours per day and excessive daytime sleepiness are significantly associated with continued dangerous driving. Wada et al[13] used data on 23 patients with cervical spinal cord injury to explore the situation of injury during work in an orchard, presenting that the frequency of cervical spinal stenosis positively correlates with farmers'age. Yanar et al[14] explored the relationship between supervisor safety support and occupational health and safety (OHS) for 2390 workers who worked over 15 hours per week. The results show that enhancing the supervisor's safety support effectively reduces the risk of injury.

On the other hand, some scholars have also explored the relation of working environment and work injury in different occupations, such as Blank et al[15] utilized data envelopment analysis (DEA) on the injury rate and annual injury rate at each stage and explored the impact of working hours and output on the increased risk of injury. The results show that automated production can reduce injuries. Larsson and Field[16] discussed occupational injury risks in the construction industry of Victoria from 1996 to 1998, with results noting that falling from a height is a major serious injury problem in the construction industry. Mark et al[17] explored the impact of American staffing and work engagement on nurse injuries. Their results show that work engagement positively relates to nurse safety. Myers et al[18] discussed the risk of informal social relations harming medical staff, noting that social relations have a significant relationship with job positions. In addition, social norms and employee interactions also affect the risk of medical staff causing injuries. Kumar et al[19] analyzed the use of manual tools that cause injuries in Indian farms. The results show that the incidence of injuries caused by manual tools has reduced the productivity of Indian farms. Yi et al[20] investigated the impact of accident prevention activities on occupational injury and disease incidence through a survey of occupational safety and health trends from 2003 to 2007. The results offer evidence that prevention activities can help reduce the incidence of occupational injuries and diseases. Fogleman et al[21] used acute injury data of a smelter from 1997 to 1999 to explore the effects of outdoor temperature, workplace, and age of workers on the incidences of injury. Age significantly affects the incidences of acute injuries. Fekedulegn et al[22] explored the relationship between physical and mental illnesses and occupational stressors, finding that high-level workplaces can reduce the incidence of work-related injuries. Nerbass et al[23] used occupational heat stress to discuss the health effects of workers exposed to high temperature work, producing findings that most workers are affected by high temperatures that seriously affect kidney function. Golabchi et al[24] proposed a comprehensive preventive design method to discuss the safety factors affecting construction workers. Their results show that manual operations can effectively improve worker safety. Sun et al[25] evaluated the performance of occupational safety on Germany's carpentry and metal processing industry, finding that occupational safety and health monitoring and assessment tool can effectively monitor workplace safety. Urtasuna and Nuñeza[26] collected data on 20 000 European workers in 2010, analyzed the impact of hard work on occupational health, and found that hard work damages health. Chandler and Bunn[27] discussed the injury factors of road rescue trailer operators, finding that the main sources of injury are being hit. Hanvold et al[28] examined the risk factors of occupational accidents and diseases of young workers in Nordic countries from 1994 to 2014, finding that mechanical, psychosocial, and organizational factors positively correlate with injury risks. Dos Santos and Mendes[29] used DEA to analyze the possibility of musculoskeletal diseases injuring miners. The research results present that treatments in the workplace can improve employee satisfaction and productivity. Jones et al. (2020) explored the relationship between young people's work experience and the risk of injury. Their results imply that safety can be improved by training and supervising young people.

The main research direction of past literature takes the perspective of work safety and health to explore the impact of work injuries on different occupations,[6,8,9,25] with less discussions on economic, social, medical, and environmental pollution issues. Regarding the methods of discussing work safety and health issues, most research has used regression analysis and statistical sampling analysis, employing static models.[8,10,12,20] Past research has lacked dynamic time analysis, failed to understand the sustainable development of society and economy, and did not consider welfare factors and environmental pollution issues that affect the overall society. Therefore, this study proposes a modified undesirable two-stage dynamic exogenous DEA model to explore the economic, social, medical, and environmental efficiencies of 30 provinces in China.

This study offers 3 contributions to the literature. First, in addition to discussing economic, social, and environmental efficiencies, this study analyzes the impact of government-invested welfare insurance such as work injury and medical care on professional labor efficiency in order to discuss the effectiveness of economic, social, medical, and environmental aspects. Second, we explore the effect on regions' economic and social efficiencies under exogenous environmental conditions. Third, considering dynamic changes, we propose a modified undesirable two-stage dynamic exogenous DEA model to solve for the lack of static analysis. This study employs data from 30 provinces in China from 2013 to 2017, with Production stage as the first stage and Social Insurance Treatment stage as the second stage. In the production stage, employed population is an input, GDP is an output, and the linking variable between the Production stage and Social Insurance Treatment stage is number of work-related injuries. In the Social Insurance Treatment stage (second stage), work injury insurance expenditure and medical insurance expenditure are inputs, and the outputs are Work injury insurance benefits and Number of Rescue invalid deaths. The Carry-over variable is fixed assets, and the Exogenous Variable is AQI.

Methods

Farrell[30] first proposed the concept of an efficiency frontier to assess efficiency, and Charnes et al[31] extended Farrell's theoretical results to multiple inputs and multiple outputs. Banker, Charnes, and Cooper set up the BCC (Banker, Charnes, and Cooper) model, which can determine whether the returns to scale are increasing or fixed. Tone[32] proposed non-radial and non-oriented estimation methods through slacks to solve the problem in which an input or output cannot be adjusted by equal proportions to achieve optimal efficiency, which is called the Slacks-Based Measure (hereinafter, SBM). After the introduction of CCR (Charnes, Cooper and Rhodes), BCC, and SBM approaches, subsequent scholars proposed many ways to improve efficiency evaluation methods, such as the super data envelopment method, hybrid data envelopment method, network data envelopment method, two-stage data envelopment method, and 3-stage data envelopment method. However, the above models are mainly based on static analysis. Kloop[33] first proposed window analysis for dynamic models, while Färe and Grosskopf[34] were the first to put inter-connecting activities into a dynamic model. Subsequent developments include Nemotoa and Goto.[35] Amirteimoori[36] defined the DEA model to evaluate dynamic income efficiency, which was modified and expanded by Färe and Grosskopf.[37]

Tone and Tsutsui[38] extended the model to a dynamic analysis of the slacks-based measure. As traditional DEA fails to analyze the efficiency of individual departments, Färe et al[39] proposed a network DEA model. Technology here is regarded as a sub-decision unit (Sub-DMU), and traditional CCR and BCC models are used to find the optimal solution. Compared with the traditional DEA model, these secondary production technologies are identified as black boxes. Conversely, the network DEA model uses these secondary production technologies to discuss the impact of input allocation and intermediate finance on the production process, instead of treating them as a black box. Tone and Tsutsui[40] proposed a weighted slack-based measures (WEB) network DEA model, using the linkage between the departments of the decision-making unit as the analysis basis, considering each department as a Sub-DMU, and then using the SBM model to find the best solution. DEA fails to analyze the efficiency of individual departments, and so there is a Network DEA method. At the same time, a company's operations can span several time periods, and so there must be a dynamic DEA model to analyze this situation.

Tone and Tsutsui[41] proposed a weighted slack-based measure Dynamic Network DEA model, using the linkage between the departments of the decision-making units as the analysis basis of the Network DEA model and treating each department as a Sub-DMU. Carry-over activities are the linkage. Tone and Tsutsui's[41] dynamic network DEA model does not consider an exogenous variable and undesirable output factors. In order to solve for exogenous variable and undesirable output factors and multi-stage problems, this study combines the Tone and Tsutsui[41] dynamic network DEA model and exogenous variable and undesirable output factors and proposes the two-stage undesirable dynamic exogenous DEA model to discuss the economic, social, medical, and environmental efficiencies of 30 provinces in China.

Two-Stage Undesirable Dynamic Exogenous DEA Model

Suppose there are n *DMU*s ($j=1,...,n$), with each one having k divisions ($k=1,...,K$) and T time periods ($t=1,...,T$). Each *DMU* has an input and output at time period t and a carry-over (link) to the next $t+1$ time period.

We set m_k and r_k to represent the inputs and outputs in each division K, with $(k, h)i$ representing divisions k to h, and L_{hk} are the k and h division set. The inputs, outputs, links, and carry-over definitions are outlined in the following paragraphs.

Regarding the assumptions of the two-stage model, the variables are explained as follows. At production stage, X^t_{1good} is employed population as input. Y^t_{1good} is GDP desirable output. $Z^t_{(12)in}$ is the link between production stage and social insurance stage. At social insurance stage: X^t_{2good} is work injury insurance expenditure and medical insurance expenditure as input. Y^t_{2good} is labor benefit from work injury insurance, Y^t_{2bad} is number of rescue invalid deaths as undesirable output, $Z^{(t,(t+1))}_{ok_i input}$ (carry-over) is investment in fixed assets. This model takes exogenous variable as external environmental factor, E^t is AQI (air quality index).

The following is the non-oriented model:

(a) Objective function

Overall efficiency:

$$\theta_0^* = \min \frac{\sum_{t=1}^{T} W^t \left[\sum_{k=1}^{K} W^k \left[1 - \frac{1}{m_k + linkin_k + ninput_k} \left(\sum_{i=1}^{m_k} \frac{S_{iok}^{t-}}{x_{iok}^t} + \sum_{(kh)_l=1}^{linkin_k} \frac{s_{o(kh)_l in}^t}{z_{o(kh)_l in}^t} + \sum_{k_l}^{ninput_k} \frac{s_{ok_l input}^{(t,t+1)}}{z_{ok_l input}^{(t,t+1)}} \right) \right] \right]}{\sum_{t=1}^{T} W^t \left[\sum_{k=1}^{K} W^k \left[1 + \frac{1}{r_{1k} + r_{2k}} \left(\sum_{r=1}^{r_{1k}} \frac{s_{rokgood}^{t+}}{y_{rokgood}^t} + \sum_{r=1}^{r_{2k}} \frac{s_{rokbad}^{t-}}{y_{rokbad}^t} \right) \right] \right]} \tag{1}$$

Subject to:
production stage

$$x_{o1}^t = X_1^t \lambda_1^t + s_{1o}^{t-} (\forall t); \tag{2}$$

$$y_{o1good}^t = Y_{1ogood}^t \lambda_1^t - s_{1ogood}^{t+} (\forall t) \tag{3}$$

$$\lambda_1^t \geq 0,\ s_{1o}^{t-} \geq 0, s_{1ogood}^{t+} \geq 0, (\forall t) \tag{4}$$

social insurance stage

$$x_{o2}^t = X_2^t \lambda_2^t + s_{2o}^{t-} (\forall t) \tag{5}$$

$$y_{o2good}^t = Y_{2good}^t \lambda_2^t - s_{2ogood}^{t+} (\forall t) \tag{6}$$

$$y_{o2bad}^t = Y_{2bad}^t \lambda_2^t + s_{2obad}^{t-} (\forall t) \tag{7}$$

$$\lambda_2^t \geq 0,\ s_{2o}^{t-} \geq 0,\ s_{2ogood}^{t+} \geq 0,\ s_{2obad}^{t+} \geq 0, (\forall t) \tag{8}$$

$$\mathrm{E}_{\mathrm{ok}}^t = E_k^t \lambda_{\mathrm{k}}^{\mathrm{t}} \qquad (\forall \mathrm{k}, \forall \mathrm{t},) \tag{9}$$

$$e\lambda_k^t = 1 \quad (\forall k, \forall t) \tag{10}$$

$$Z_{o(12)in}^t = Z_{(12)in}^t \lambda_1^t - S_{o(12)in}^t \ ((1,2)in) \tag{11}$$

$$\sum_{j=1}^{n} Z_{jk_l\alpha}^{(t,(t+1))} \lambda_{jk}^t = \sum_{j=1}^{n} z_{jk_l\alpha}^{(t,(t+1))} \lambda_{jk}^{t+1} \quad (\forall k; \forall k_l; t = 1, \ldots, T-1) \tag{12}$$

$$Z_{ok_l input}^{(t,(t+1))} = \sum_{j=1}^{n} z_{jk_l input}^{(t,(t+1))} \lambda_{jk}^t + s_{ok_l input}^{(t,(t+1))} \quad k_l = 1, \ldots, ngood_k; \forall k; \forall t) \tag{13}$$

(b) Period and division efficiencies

Period and division efficiencies are as follows:

(b1) Period efficiency:

$$\partial_0^* = \min \frac{\sum_{k=1}^{K} W^k \left[1 - \frac{1}{m_k + linkin_k + ngood_k} \left(\sum_{i=1}^{m_k} \frac{S_{iok}^{t-}}{x_{iok}^t} + \sum_{(kh)_l=1}^{linkin_k} \frac{s_{o(kh)_l in}^t}{z_{o(kh)_l in}^t} + \sum_{k_l}^{ngood_k} \frac{s_{ok_l good}^{(t,t+1)}}{z_{ok_l good}^{(t,t+1)}} \right) \right]}{\sum_{k=1}^{K} W^k \left[1 + \frac{1}{r_{1k} + r_{2k}} \left(\sum_{r=1}^{r_{1k}} \frac{s_{rokgood}^{t+}}{y_{rokgood}^t} + \sum_{r=1}^{r_{2k}} \frac{s_{rokbad}^{t-}}{y_{rokbad}^t} \right) \right]} \tag{14}$$

$X_{i\ good}^t$ is desirable input, $Y_{r\ good}^t$ is desirable output, $Y_{r\ bad}^t$ is undesirable output. W^k is the weight of different stage.

(b2) Division efficiency:

$$\varphi_0^* = \min \frac{\sum_{t=1}^{T} W^t \left[1 - \frac{1}{m_k + linkin_k + ninput_k} \left(\sum_{i=1}^{m_k} \frac{S_{iok}^{t-}}{x_{iok}^t} + \sum_{(kh)_l=1}^{linkin_k} \frac{s_{o(kh)_l in}^t}{z_{o(kh)_l in}^t} + \sum_{k_l}^{ninput_k} \frac{s_{ok_l input}^{(t,t+1)}}{z_{ok_l input}^{(t,t+1)}} \right) \right]}{\sum_{t=1}^{T} W^t \left[1 + \frac{1}{r_{1k} + r_{2k}} \left(\sum_{r=1}^{r_{1k}} \frac{s_{rokgood}^{t+}}{y_{rokgood}^t} + \sum_{r=1}^{r_{2k}} \frac{s_{rokbad}^{t-}}{y_{rokbad}^t} \right) () \right]} \tag{15}$$

Table 1. Input and Output Variables.

	Input variables	Output variables	Link	Carry-over	Exogenous
Stage 1	Employed population	GDP	Number of work-related injuries	Fixed assets	AQI
Stage 2	Work injury insurance expenditure	Labor benefit from work injury insurance			
	Medical insurance expenditure	Number of rescue invalid deaths			

Source. China Statistical Yearbook Database.

Note. **The first stage: production stage**—*Input variables*: (A) Employed population (unit: 10 000 people) covers the number of urban labor registrations in each area at the end of each year. *Output variables*: (B) Regional GDP (regional GDP) (unit: 100 million RMB) encompasses the regional GDP of each province, municipality, and autonomous region. **Link production stage and social insurance stage**: (C) Number of work-related injuries (unit: person) includes casualties that are directly or indirectly caused by work in each area in the current period. **The second stage: social insurance stage**—*Input variables*: (D) Work injury insurance expenditure (unit: 100 million RMB) is the basic fund for industrial injury insurance in various regions. (E) Medical insurance expenditure (unit: 100 million RMB) is the basic fund expenditure of urban basic medical insurance in various regions. *Output variables*: (F) Labor benefit from work injury insurance (unit: 10 000 people) covers the number of relatives of workers injured or killed in various regions who should be compensated according to law. (G) Number of rescue invalid deaths (unit: person), which is the number of people who died of sudden illness during working hours and positions or died within 48 hours after a rescue failed. *Carry-over*: (H) Fixed assets (unit: 100 million RMB) cover investments of the whole society in each region. *Exogenous*: (I) AQI is air quality index, a measure of pollutant concentration, including particulate matters (PM2.5, PM10), sulfur dioxide (SO_2), ozone (O_3), nitrogen dioxide (NO_2), and carbon monoxide.

$X^t_{i\,good}$ is desirable input, $Y^t_{r\,good}$ is desirable output, $Y^t_{r\,bad}$ is undesirable output, W^t is period weight.

(b3) Division period efficiency:

$$\rho_0^* = \min \frac{1 - \dfrac{1}{m_k + linkin_k + ninput_k}\left(\sum_{i=1}^{m_k} \dfrac{S^{t-}_{iok}}{x^t_{iok}} + \sum_{(kh)_i=1}^{linkin_k} \dfrac{s^t_{o(kh)_i in}}{z^t_{o(kh)_i in}} + \sum_{k_i}^{ninput_k} \dfrac{s^{(t,t+1)}_{ok_i input}}{z^{(t,t+1)}_{ok_i input}}\right)}{1 + \dfrac{1}{r_{1k} + r_{2k}}\left(\sum_{r=1}^{r_{1k}} \dfrac{s^{t+}_{rokgood}}{y^t_{rokgood}} + \sum_{r=1}^{r_{2k}} \dfrac{s^{t-}_{rokbad}}{y^t_{rokbad}}\right)} \qquad (16)$$

According to the above results, the overall efficiency, the period efficiency, the division efficiency and division period efficiency can be obtained.

Input, Desirable Output, and Undesirable Output Efficiency

Hu and Wang's[42] total-factor energy efficiency index is used to overcome any possible biases in traditional energy efficiency indicators, for which there are key efficiency models; expenditure on work-related injury insurance and medical insurance; number of work-related injuries; labor benefit from work injury insurance; Number of Rescue invalid death. The efficiency models are defined as follows.

$$\text{Input efficiency} = \frac{\text{Target input}}{\text{Actual input}}$$

$$\text{Undesirable output efficiency} = \frac{\text{Target Undesirable output}}{\textit{Actual}\ \text{Undesirable}\ \textit{output}}$$

$$\text{Desirable output efficiency} = \frac{\text{Target Desirable output}}{\textit{Actual}\ \text{Desirable}\ \textit{output}}$$

If the target inputs equal the actual inputs, then the efficiencies are 1, which indicates overall efficiency. However, if the target inputs are less than the actual inputs, then the efficiencies are less than 1, which indicates overall inefficiency.

If the target desirable outputs are equal to the actual desirable outputs, then the efficiencies are 1, indicating overall efficiency. However, if the target desirable outputs are more than the actual desirable outputs, then the efficiencies are less than 1, indicating overall inefficiency.

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Data and Variables

This study collects data from 2013 to 2017 of China Statistical Yearbook and China Labor Statistics Yearbook and uses panel data to conduct empirical research on 30 provinces, autonomous regions, and municipalities in the country. AQI pollutant data come from the report of China Environmental Protection Agency. Table 1 lists various variables in the study.

Through the modified undesirable two-stage dynamic DEA model, we use AQI as an exogenous variable, and number of work-related injuries is used as an intermediate output variable to analyze whether there is estimation bias in the efficiency analysis to evaluate economy, society, medical treatment, and work injury efficiencies. This study designs the Framework Model of the modified Undesirable two-stage Dynamic DEA model (see Figure 1). The first stage is the production stage, the input variable is employed population, and the output variable is GDP, and then the second stage is connected through the link variable of number of work-related injuries. The second stage is the social

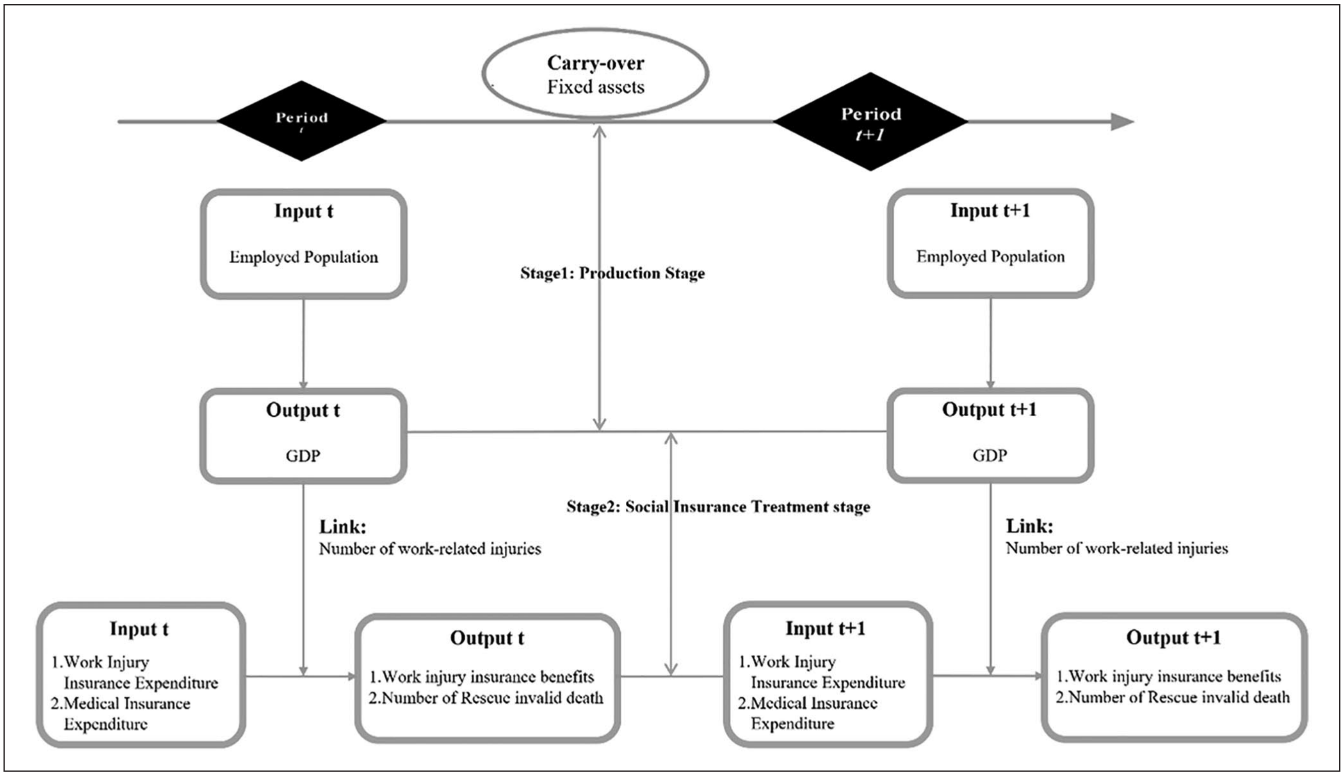

Figure 1. Framework model.

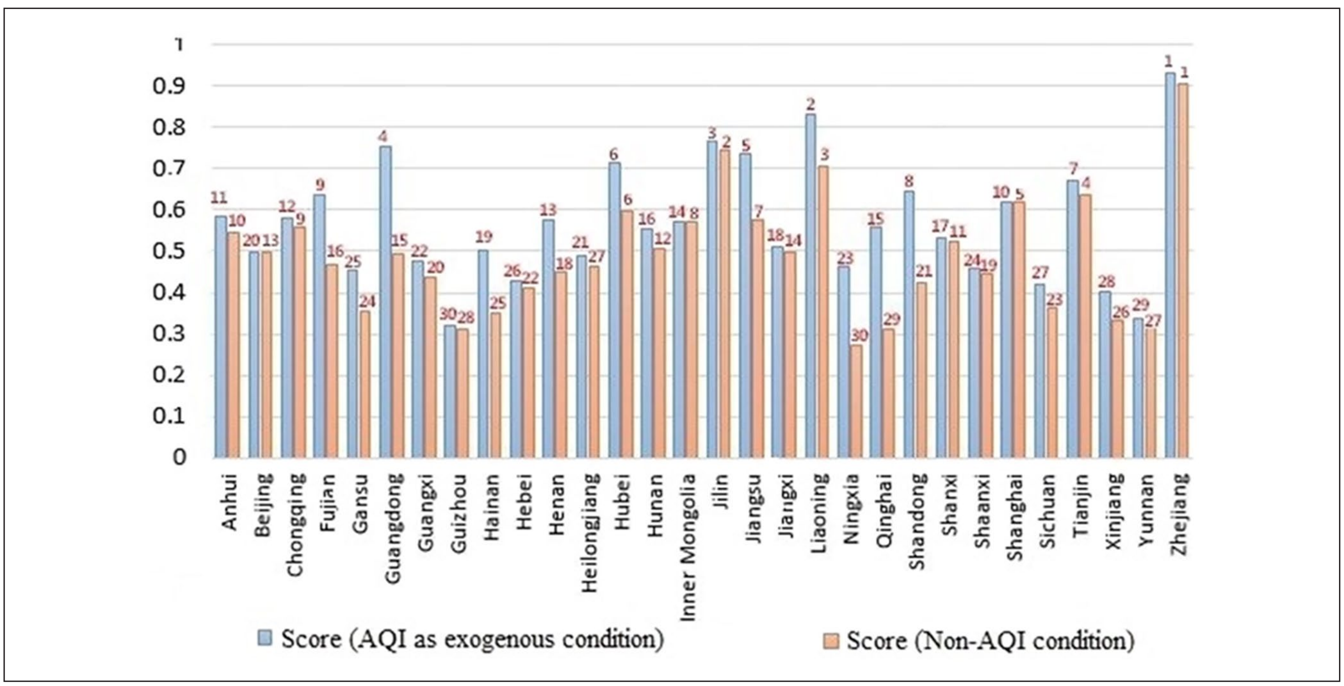

Figure 2. Overall 30 provinces' efficiency ranking analysis comparison by considering AQI as an exogenous condition in 2013 to 2017.

insurance stage, the input variables are work injury insurance expenditure and medical insurance expenditure, and the output variables are labor benefit from work injury insurance and Number of Rescue invalid deaths, with the carry-over being fixed assets.

Empirical Study

Overall Efficiency Ranking Analysis

From Figure 2, we know that the Air Quality Index (AQI) is divided into 2 exogenous variables under different analysis,

Table 2. 30 Provinces' Yearly Efficiency Ranking Comparison in 2013 to 2017.

	AQI under exogenous condition						Non-AQI exogenous condition					
DMU	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph
Anhui	15	12	20	16	12		11	9	13	9	7	
Beijing	20	16	16	19	18		13	10	7	13	10	
Chongqing	19	14	23	21	4		12	8	16	14	2	
Fujian	12	15	12	11	13		19	18	15	16	15	
Gansu	11	25	28	22	27		25	22	27	20	30	
Guangdong	5	3	3	4	3		15	13	12	15	12	
Guangxi	28	28	17	20	19		21	22	10	19	16	
Guizhou	30	30	29	30	29		30	29	29	26	25	
Hainan	21	26	14	14	10		27	26	22	23	17	
Hebei	25	21	24	28	28		18	16	21	24	24	
Henan	14	9	11	10	15		24	25	5	11	19	
Heilongjiang	4	24	27	25	23		5	19	23	22	20	
Hubei	6	18	7	1	7		4	15	14	2	11	
Hunan	24	17	19	6	20		17	12	19	4	14	
Inner Mongolia	17	13	10	12	16		10	6	4	7	8	
Jilin	3	10	2	15	1		3	7	2	10	1	
Jiangsu	9	4	4	5	2		14	11	9	12	6	
Jiangxi	13	19	21	23	22		8	14	18	18	21	
Liaoning	1	2	5	3	5		2	5	8	3	3	
Ningxia	22	20	15	18	17		29	30	25	30	28	
Qinghai	18	11	13	17	14		28	27	28	27	27	
Shandong	8	6	6	9	9		20	20	20	21	18	
Shanxi	7	7	22	13	26		6	3	17	8	23	
Shaanxi	23	22	18	24	21		16	17	11	17	13	
Shanghai	16	8	8	8	8		9	4	3	5	4	
Sichuan	27	27	26	26	24		22	23	26	25	22	
Tianjin	10	5	9	7	6		7	2	6	6	5	
Xinjiang	26	23	25	27	25		23	24	24	29	26	
Yunnan	29	29	30	29	30		26	28	30	28	29	
Zhejiang	1	1	1	1	11		1	1	1	1	9	

and the efficiency ranking is compared. The results are as follows. (1) When AQI is considered as an exogenous variable, the top ten provinces or municipalities in total efficiency are Zhejiang, Liaoning, Jiling, Guangdong, Jiangshu, Hubei, Tianjin, Shangdong, Fujian, and Shanhai. When Liaoning, Guangdong, Jiangshu, Shangdong, and Fujian do not consider AQI exogenous conditions, the efficiency ranking is underestimated. Guangdong ranks 15th, Shangdong ranks 21th, and Fujian ranks 16th. When the above cities consider AQI as exogenous, their efficiency rankings have greatly improved. Similarly, the efficiency rankings of several regions such as Henan, Qinghai, Hainan, and Ningxia are also underestimated. The efficiency ranking of Qinghai has even increased from the top 29 to 15 in consideration of AQI. On the contrary, the efficiency rankings of Shanghai, Beijing, Heilongjiang and Jiangxi are overestimated. Shanghai ranks 5th without considering the efficiency of AQI as an exogenous condition, and it drops to 10th after consideration. (2) Regardless of whether AQI is considered or not, Zhejiang, Liaoning, and Jilin rank the top in efficiency ranking. Whether AQI is considered or not has no effect on Xinjiang, Yunnan, and Guizhou, which are ranked lower in efficiency. (3) Whether AQI is considered as an exogenous variable, the results are different. Without considering AQI, the efficiency ranking of each region can be overestimated or underestimated.

The above presents further analysis of the overall efficiency ranking of each region. We shall continue to discuss the intertemporal impact of efficiency values and efficiency rankings over time.

Yearly Efficiency Ranking Comparison

Table 2 presents the efficiency rankings of the 30 provinces from 2013 to 2017. It is divided into 2 parts. One part considers the efficiency ranking of AQI under exogenous conditions, and the other part considers regional efficiency ranking without considering AQI under exogenous

Table 3. Work Injury Insurance Expenditure's Total-Factor Efficiency Analysis.

	AQI under exogenous condition						Non-AQI exogenous condition					
DMU	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph
Anhui	1	1	15	1	1		1	1	10	1	1	
Beijing	27	28	12	30	29		27	28	9	28	27	
Chongqing	9	7	25	14	1		9	6	21	11	1	
Fujian	12	22	14	13	13		12	21	15	12	15	
Gansu	18	10	26	10	25		18	9	24	8	22	
Guangdong	10	5	1	8	1		11	10	14	14	18	
Guangxi	11	9	13	11	1		10	8	11	9	1	
Guizhou	29	29	30	29	28		29	29	29	27	26	
Hainan	26	20	1	9	1		26	24	1	21	11	
Hebei	21	19	27	25	27		21	16	27	23	24	
Henan	22	23	7	27	19		22	22	6	25	14	
Heilongjiang	1	15	29	15	22		1	15	30	13	19	
Hubei	1	11	16	1	10		1	11	13	1	7	
Hunan	14	13	6	23	26		14	25	4	20	23	
Inner Mongolia	24	25	23	1	16		23	12	23	1	10	
Jilin	1	6	1	7	1		1	5	1	7	1	
Jiangsu	23	27	21	18	8		24	27	26	19	8	
Jiangxi	1	8	17	12	17		1	8	12	10	12	
Liaoning	28	4	20	1	1		28	4	18	1	1	
Ningxia	30	30	1	17	12		30	30	7	30	29	
Qinghai	25	24	10	22	23		25	23	28	29	28	
Shandong	20	16	23	21	11		20	17	16	18	20	
Shanxi	17	1	28	1	30		17	1	25	1	30	
Shaanxi	17	21	9	26	18		17	20	5	24	13	
Shanghai	28	26	11	24	9		28	26	8	22	6	
Sichuan	13	12	19	16	21		13	13	19	15	21	
Tianjin	15	14	18	19	15		15	14	17	16	16	
Xinjiang	19	17	24	28	24		19	18	22	26	25	
Yunnan	16	18	22	20	20		16	19	20	17	17	
Zhejiang	1	1	1	1	14		1	1	1	1	9	

conditions. From the efficiency ranking under the 2 conditions, we clearly see that the efficiency ranking is underestimated and overestimated.

We first we discuss the provinces with the highest efficiency rankings in Zhejiang, Guangdong, Jiangsu, Liaoning, and Shanghai after considering changes in AQI during 2013 to 2017. It means that after considering the AQI condition, the efficiency performance of each region gradually approaches the optimal state. Regardless of whether AQI is considered exogenous or not, after the changes from 2013 to 2016, Zhejiang ranks 1st in efficiency. It means that in the past few years, whether AQI is considered exogenous or not, it has no impact on Zhejiang. The efficiency rankings of Shanghai and Shandong are relatively stable. In other regions, without considering AQI as an exogenous condition, the efficiency rankings are underestimated. When AQI is an exogenous variable, Jilin improves from 15th in 2016 to 1st in 2017, Chongqing from 21st in 2016 to 4th in 2017, while Shanxi falls from 13th to 26th in 2017. From the above areas we find that the efficiency ranking is overestimated compared to the efficiency ranking without considering the AQI condition.

From Table 3, regardless of whether AQI is an exogenous condition, Gansu, Hebei, Heilongjiang, and Shanxi lag behind in efficiency ranking. Without considering that AQI is exogenous, the efficiencies of Gansu and Shanxi are underestimated, while the efficiencies of Hebei and Heilongjiang are overestimated. After considering AQI as an exogenous condition, the efficiency ranking of each region can be revised.

Table 2 presents that the regional efficiency rankings have improved in Guangxi, Hainan, Fujian, and Ningxia. In the above areas, when considering AQI, there is a phenomenon of overestimation and underestimation of regional efficiency rankings. From the time trend of 2013 to 2017, the number of regions ranked first in efficiency also changes, and so the efficiency ranking among various regions in China is revised. AQI has an impact on the ranking of regional medical work injury efficiency.

Total-Factor Efficiency Analysis Over Time

Under the condition that AQI is an exogenous variable, we discuss the regional efficiency ranking of each province through Total-Factor Efficiency Analysis and compare the efficiency ranking obtained without considering AQI. Based on the analysis and ranking differences under the 2 conditions, we analyze the input variables work injury insurance expenditure, medical insurance expenditure, and labor benefit from work injury insurance, the undesirable output of Number of Rescue invalid deaths, and the number of work-related injuries. The calculation method of the efficiency ranking bias value is based on the efficiency ranking without considering AQI as the exogenous condition, minus the efficiency ranking considering AQI as the exogenous condition. The difference in value between the 2 groups of efficiency rankings is obtained in order to judge whether AQI has an impact on rankings.

Total-factor efficiency analysis of work injury insurance expenditure and medical insurance expenditure. Table 3 shows the gap between the total factor efficiency of Work injury insurance expenditure when considering AQI and when not considering AQI as an exogenous condition. Whether we consider the 2 exogenous conditions of AQI, the efficiency rankings of Jiangsu and Shanxi do not change, and the top ranking regions are Anhui, Zhejiang, and Jilin. Guizhou and Xinjiang lag behind in total factor efficiency rankings. This indicates that the total factor efficiency in these regions, regardless of whether AQI is considered an exogenous condition, does not affect the best and worst performing provincial efficiency rankings.

We see that Liaoning's 2015 work injury insurance expenditure efficiency value ranking is overestimated, but from 2016 to 2017, we see that regardless of whether AQI is considered, the total factor efficiency ranking rises to 1st. Shanxi's work injury insurance expenditure efficiency ranking has changed a lot, from 1st in 2014 to 28th in 2015, then to 1st in 2016, and down to 30th in 2017. This shows that the efficiency of work injury insurance expenditure in Shanxi is still in the process of adjustment. Without considering AQI, the provinces that underestimate the efficiency of work injury insurance expenditures are Hainan and Guangdong. The provinces with underestimated work injury insurance expenditure efficiency are Fujian, Ningxia, Qinghai, Shandong, Tianjin and Xinjiang. Ningxia is the region with the largest difference in efficiency underestimation. Beijing, Gansu, Hebei, Henan, Heilongjiang, Hubei, Hunan, Inner Mongolia, Shaanxi, Shanghai, Yunnan, and Zhejiang exhibit overestimation bias in the efficiency of work injury insurance. In 2017, Hubei, Hunan and Zhejiang's work injury insurance expenditure efficiencies drop. Under the condition of using AQI as an exogenous variable, the ranking bias of work injury insurance expenditure efficiency can be corrected as reference for local governments on medical policies.

Table 4 shows the rankings of efficiency for the full factor analysis of medical insurance expenditure of 30 provinces in China during 2013 to 2017. Whether considering the 2 exogenous conditions of AQI, the efficiency rankings of Anhui and Zhejiang rank 1st, while Beijing remains at the bottom. The efficiency ranking of medical insurance in other provinces is both underestimated and overestimated. The efficiency of medical insurance expenditure in Shanxi is among the top ones in 2013 and 2016, but in 2017, regardless of whether AQI exogenous conditions are considered, its efficiency rank drops. The efficiency of Heilongjiang also drops from 1st in 2013 to 10th in 2017, and the efficiency declines. Ningxia ranks 8th in efficiency when AQI is not considered in 2017, but it drops to 28th after considering AQI, which is significantly overestimated. Shanghai, Hunan, Jiangxi, Shaanxi and other regions underestimate the efficiency of medical insurance spending. In 2017, regardless of whether AQI is considered, the efficiencies of the medical insurance expenditures of Jilin, Liaoning, and Chongqing rise to first place.

Total-factor efficiency analysis of the Number of Rescue invalid deaths. Table 5 shows the total-factor efficiency analysis of the Number of Rescue invalid deaths. There is bias in efficiency ranking with and without considering AQI as an exogenous condition. The results are consistent with Table 3's rankings of efficiencies of work injury insurance expenditures. This phenomenon may indicate that the improvement of AQI relates to the number of Rescue invalid deaths, and that China still needs to continue to improve the efficiency of work injury insurance expenditures. It also needs to invest in air treatment for a long time to improve employees' working environment.

Table 6 shows the total factor efficiency of labor benefit from work injury insurance. Compared with other indicators, AQI has a relatively small effect on the total factor efficiency of labor benefit from work injury insurance. From 2013 to 2017, regardless of whether the external conditions of AQI are considered, the efficiency values of Anhui, Fujian, Gansu, Guizhou, Hebei, Heilongjiang, Hubei, Hunan, Liaoning, Shanxi, Tianjin and Zhejiang are 1st. Beijing, Shanghai, and Shaanxi maintain a stable ranking, and whether AQI is considered has no impact on these regions. The efficiency ranking of labor benefit from work injury insurance in Xinjiang and Chongqing ranks 1st from 2013 to 2016, regardless of whether AQI is considered. Chongqing's efficiency value in 2017 ranks 1st when AQI is not considered, but after consideration, it drops to 30th, with the rank obviously being overestimated. The efficiency values of Hainan, Guangdong, Shandong, and Qinghai are overestimated in 2017. Compared with other indicators, AQI has less influence on the efficiency of labor benefit from work injury insurance. The main reason is that the labor benefit from work injury insurance of each province itself benefits from national policies, and its degree of influence is basically the same between provinces.

Table 4. Medical Insurance Expenditure's Total-Factor Efficiency Analysis.

	AQI under exogenous condition						Non-AQI exogenous condition					
DMU	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph
Anhui	1	1	11	1	1		1	1	5	1	1	
Beijing	30	30	29	30	30		30	30	27	30	30	
Chongqing	11	8	27	13	1		11	7	20	10	1	
Fujian	17	11	14	10	12		15	10	13	9	11	
Gansu	23	1	25	18	29		23	1	23	17	29	
Guangdong	12	7	6	6	16		17	15	21	20	5	
Guangxi	22	24	28	23	19		22	24	26	24	24	
Guizhou	13	13	20	12	6		13	11	15	11	7	
Hainan	29	29	22	29	21		29	29	19	28	20	
Hebei	9	4	9	22	14		9	5	9	19	19	
Henan	19	17	25	14	26		18	16	25	12	27	
Heilongjiang	1	15	24	21	10		1	14	22	18	10	
Hubei	1	20	21	1	20		1	19	17	1	25	
Hunan	10	5	5	1	8		10	1	11	1	10	
Inner Mongolia	26	27	10	27	27		26	26	7	22	28	
Jilin	1	9	1	11	1		1	8	1	8	1	
Jiangsu	16	10	13	9	13		16	12	16	13	6	
Jiangxi	1	6	12	7	17		1	6	8	7	21	
Liaoning	1	12	17	8	1		1	9	14	6	1	
Ningxia	28	28	8	20	28		28	28	12	29	8	
Qinghai	27	26	18	26	22		27	27	30	26	18	
Shandong	15	22	16	25	18		14	22	24	23	17	
Shanxi	1	1	4	1	11		1	1	4	1	15	
Shaanxi	20	18	7	16	7		19	17	6	14	12	
Shanghai	25	19	15	17	9		24	18	10	15	13	
Sichuan	18	16	23	24	23		20	20	28	25	23	
Tianjin	21	23	26	19	15		21	23	25	21	16	
Xinjiang	24	25	30	28	24		25	25	29	27	22	
Yunnan	14	14	19	15	25		12	13	18	16	26	
Zhejiang	1	1	1	1	5		1	1	1	1	9	

Total-factor efficiency analysis of the number of work-related injuries. From Table 7, when the efficiency ranking of number of work-related injuries does not consider AQI as an exogenous condition, the efficiency rankings of all provinces are underestimated and overestimated. Regardless of whether AQI exogenous conditions are considered, Beijing, Heilongjiang, Hubei, Jilin, and Inner Mongolia rank 1st in efficiency for 5 years. AQI changes do not affect the efficiency ranking of these provinces. In 2017, Shanghai, Chongqing, and Shaanxi achieve 1st place regardless of whether AQI is considered an exogenous efficiency ranking. The efficiency improvement effect of these provinces is more obvious and leads other cities. Zhejiang's efficiency ranking falls to last place in 2017 under declining efficiency.

Regardless of the exogenous conditions of AQI, Guangdong, Fujian, Yunnan, Ningxia, Tianjin, Jiangsu, Sichuan, Shandong, Shanxi, Ningxia, and Qinghai have significantly underestimated rankings and large bias values. The inclusion of AQI in the analysis of the efficiency ranking of work-related injuries in these areas obviously changes its original efficiency ranking. Guizhou, Hebei, Hunan, and Xinjiang present overestimated efficiency. This shows that AQI has a significant impact on the efficiency ranking of the number of work-related injuries in various provinces of China.

Policy Recommendation and Discussion

Discussion

The problem of air pollution has become the focus of society in recent years, and economic development models are unsustainable due to the cost of environmental pollution. Severe air pollution has brought greater pressure on the lives and health of residents. It not only directly harms human health and is prone to cause various diseases, but also has various negative effects on people's mental health, leading to

Table 5. Total-Factor Efficiency Analysis of China 30 Provinces' Number of Rescue Invalid Deaths by Considering whether or not AQI Is Exogenous in 2013 to 2017.

	AQI under exogenous condition						Non-AQI exogenous condition					
DMU	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph
Anhui	1	1	13	1	1		1	1	11	1	1	
Beijing	23	24	1	19	19		24	24	1	17	15	
Chongqing	1	1	12	6	1		1	1	10	6	1	
Fujian	16	17	20	15	17		16	16	19	14	14	
Gansu	12	13	22	11	28		13	13	18	11	25	
Guangdong	22	16	16	20	15		17	17	26	21	23	
Guangxi	27	26	29	28	26		27	26	29	26	22	
Guizhou	25	20	25	23	24		20	19	22	20	20	
Hainan	29	29	9	24	20		29	29	6	30	30	
Hebei	15	12	26	22	22		15	12	23	19	18	
Henan	28	28	11	29	27		28	28	9	27	24	
Heilongjiang	1	14	23	13	9		1	14	20	13	9	
Hubei	1	11	24	1	14		1	11	21	1	13	
Hunan	10	5	17	1	8		12	5	14	1	8	
Inner Mongolia	26	22	8	25	30		26	23	5	22	27	
Jilin	1	9	1	10	1		1	10	1	10	1	
Jiangsu	13	7	14	8	10		10	6	12	8	11	
Jiangxi	1	8	27	9	7		1	8	25	9	7	
Liaoning	1	6	15	7	1		1	7	13	7	1	
Ningxia	30	30	7	14	16		30	30	8	28	28	
Qinghai	20	23	1	18	18		22	22	28	23	26	
Shandong	17	18	1	21	11		18	18	24	18	16	
Shanxi	1	1	18	1	21		1	1	15	1	17	
Shaanxi	21	27	10	27	25		23	27	7	25	21	
Shanghai	19	15	1	17	5		21	15	1	16	5	
Sichuan	11	10	19	12	12		11	10	16	12	10	
Tianjin	14	19	21	16	13		14	20	17	15	12	
Xinjiang	24	25	30	30	29		25	25	30	29	29	
Yunnan	18	21	28	26	23		19	21	27	24	19	
Zhejiang	1	1	1	1	6		1	1	1	1	6	

accidents at workplaces. The rapid growth of China's economy has also exacted a high environmental price. In 2011, China's carbon emissions accounted for 28% of the world's total. In 2013, China experienced severe smog and spread to 25 provinces and more than 100 large- and medium-size cities. In the 2018 global environmental performance ranking, China was 120th among 180 countries, and its AQI was 4th from last among all countries. The air pollution problem is already a serious threat to public health and economic growth, and relevant departments and local governments are paying greater attention to it. Thus, the conclusion of this research for using air pollution as an exogenous condition runs as follows.

1. AQI has a significant effect on the overall efficiency of each region. Except for Zhejiang, Liaoning and Jilin, which have always been in the top ranks, the efficiencies of other provinces are either overestimated or underestimated. From 2013 to 2017, the efficiency of work-related injuries fluctuates in various regions. After considering the exogenous conditions of AQI, a province's work injury efficiency fluctuates more between years.
2. In terms of work injury insurance expenditure, AQI has an impact on the efficiency rankings of China's 30 provinces and regions, but there are certain differences in the degree of impact. The efficiencies of work-related injury insurance expenditures in Jiangsu and Shanxi are basically not affected by AQI, while Anhui, Zhejiang, and Jilin are less affected by AQI. Fujian, Ningxia, Qinghai, Shandong, Tianjin, and Xinjiang have been greatly affected, while efficiency declines in Hubei, Hunan, and Zhejiang. There is a similar situation in medical insurance expenditure efficiency. The efficiencies of medical insurance expenditure in Anhui, Zhejiang, and Beijing, are

Table 6. Total-Factor Efficiency Analysis of Labor Benefit from Work Injury Insurance.

	AQI under exogenous condition						Non-AQI exogenous condition					
DMU	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph
Anhui	1	1	1	1	1		1	1	1	1	1	
Beijing	1	1	28	27	22		1	1	27	30	26	
Chongqing	1	1	1	1	30		1	1	1	1	1	
Fujian	1	1	1	1	1		1	1	1	1	1	
Gansu	1	1	1	1	1		1	1	1	1	1	
Guangdong	1	30	21	26	20		25	1	1	1	1	
Guangxi	1	1	1	1	26		1	1	1	1	29	
Guizhou	1	1	1	1	1		1	1	1	1	1	
Hainan	1	29	27	29	27		1	1	28	1	1	
Hebei	1	1	1	1	1		26	1	1	1	1	
Henan	1	1	29	1	21		20	1	29	1	25	
Heilongjiang	1	1	1	1	1		1	1	1	1	1	
Hubei	1	1	1	1	1		1	1	1	1	1	
Hunan	1	1	1	1	1		1	1	1	1	1	
Inner Mongolia	1	1	24	1	18		1	1	25	1	24	
Jilin	1	1	1	1	1		21	1	1	1	1	
Jiangsu	1	1	20	1	1		22	1	1	1	1	
Jiangxi	30	1	1	1	1		24	1	1	1	1	
Liaoning	1	1	1	1	1		1	1	1	1	1	
Ningxia	1	1	30	30	29		23	1	30	1	27	
Qinghai	1	1	26	28	23		28	1	1	1	1	
Shandong	1	1	22	1	24		27	1	1	1	1	
Shanxi	1	1	1	1	1		1	1	1	1	1	
Shaanxi	1	1	25	1	25		1	1	26	1	28	
Shanghai	1	1	23	1	28		1	1	24	1	30	
Sichuan	1	1	1	1	1		29	1	1	1	1	
Tianjin	1	1	1	1	1		1	1	1	1	1	
Xinjiang	1	1	1	1	19		1	1	1	1	1	
Yunnan	1	1	1	1	1		30	1	1	1	1	
Zhejiang	1	1	1	1	1		1	1	1	1	1	

basically not affected by AQI, while the efficiencies of other regions are relatively affected. The efficiencies of Heilongjiang and Ningxia decline.

3. In terms of the Number of Rescue invalid deaths, there is a large bias of efficiency rankings in the 30 provinces when considering AQI as exogenous and without considering AQI as such. The number of rescue invalid deaths is significantly affected by AQI. The efficiency rankings of the number of work-related injuries are affected by AQI, but there are also large differences in the impacts on various regions. Beijing, Heilongjiang, Hubei, Jilin, and Inner Mongolia are not affected by AQI, while other provinces are relatively affected. The improvement effect of the number of work-related injuries in Shanghai, Chongqing, and Shaanxi is more obvious, while the efficiency of Zhejiang is declining. AQI has little effect on the efficiency of labor benefit from work injury insurance.

Research Hypotheses and Limitations

This research mainly analyzes the economic, social, medical and work injury efficiency performance of various provinces in China under the influence of air pollution. Therefore, the research hypothesis is to explore the relationship between employment and work injury and medical insurance in different provinces in China, and at the same time consider and ignore the differences in external environmental impacts such as air pollution among provinces.

Limitations of model assumptions: The AQI air pollution environmental indicators are regarded as exogenous variables, and the efficiency analysis is carried out for the production stage and the social work injury and insurance stage that affect the economic development of each province. Due to the limitation of this study, it is not easy to collect data, so it does not consider the impact of other external environmental factors such as climate change or other environmental pollution in the model.

Table 7. Total-Factor Efficiency Analysis the 30 Provinces' Number of Work-Related Injuries by Considering whether or not AQI Is Exogenous during 2013 to 2017.

	AQI under exogenous condition						Non-AQI exogenous condition					
DMU	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph	2013 rank	2014 rank	2015 rank	2016 rank	2017 rank	Trend graph
Anhui	1	1	28	1	1		1	1	1	1	1	
Beijing	1	1	1	1	1		1	1	1	1	1	
Chongqing	29	27	30	30	1		24	24	30	27	1	
Fujian	1	1	1	1	1		19	15	20	22	22	
Gansu	1	1	1	1	1		1	1	17	1	1	
Guangdong	1	1	1	1	1		30	30	29	30	28	
Guangxi	1	24	1	1	1		1	23	1	17	1	
Guizhou	1	30	29	29	28		29	29	28	26	26	
Hainan	1	1	1	1	1		1	18	13	15	1	
Hebei	1	29	27	28	29		26	28	24	25	27	
Henan	1	1	25	1	1		1	17	1	1	1	
Heilongjiang	1	1	1	1	1		1	1	1	1	1	
Hubei	1	1	1	1	1		1	1	1	1	1	
Hunan	1	28	24	1	26		1	19	25	1	19	
Inner Mongolia	1	1	1	1	1		1	1	1	1	1	
Jilin	1	1	1	1	1		1	1	1	1	1	
Jiangsu	1	1	1	1	1		28	26	26	28	25	
Jiangxi	1	25	27	26	1		1	22	16	21	1	
Liaoning	1	1	1	1	1		1	1	23	1	1	
Ningxia	30	26	1	1	1		22	27	27	29	29	
Qinghai	26	1	1	1	1		20	21	15	20	21	
Shandong	1	1	1	1	1		18	14	14	16	17	
Shanxi	1	1	23	1	1		1	1	1	1	16	
Shaanxi	1	1	26	1	1		1	1	19	1	1	
Shanghai	28	1	1	1	1		1	1	1	1	1	
Sichuan	27	23	1	1	1		27	25	22	23	23	
Tianjin	1	1	1	1	1		23	16	18	18	20	
Xinjiang	1	1	1	1	27		21	1	12	24	24	
Yunnan	1	22	1	27	1		25	20	21	19	18	
Zhejiang	1	1	1	1	30		1	1	1	1	30	

Restrictions on data collection: In the early years, the statistics of various provinces in China were relatively incomplete, including air pollution environmental indicators such as AQI. The "Technical Regulation on Ambient Air Quality Index"[43] indicators are implemented in 2012 according to the "Ambient Air Quality Standards"[44] to report daily and real-time reports on the ambient air quality index and pollutant concentration. In addition, there is a time gap in statistics in various regions. For example, Tibet lacks relevant statistical data on the number of work-related injuries and work-related injury insurance benefits, so this article only collects data from 30 provinces in China from 2013 to 2017.

Policy Recommendation

Air pollution obviously affects the efficiency of medical injuries in various regions of China. These regions have improved human capital by raising environmental quality. A comprehensive evaluation of the social benefits of environmental governance investments has important policy implications.

1. Various provinces in China attract talents through substantial income and welfare benefits. If the probability of a medical accident at a workplace is high, then there is obviously a negative impact on it. Therefore, we cannot ignore the needs of employees for environmental quality and urban livability characteristics, and increasing the income of employees could make up for the negative impact of air pollution. However, improving environmental quality is still a more effective way for regions to gather human capital and promote high-quality urbanization.
2. For national and local policymakers, current air pollution is affecting economic growth. This study finds that air pollution also has a direct impact on medical insurance expenditures and the number of insurance benefits, and it also has a negative impact on

the output of workers. In addition to formulating and implementing relevant legislation, compulsory measures can be instituted such as line restrictions and production suspensions in order to improve China's environmental quality, but the air pollution problem is still not optimistic. The government should also strengthen education and publicity for people and especially for enterprises, so that they can realize that environmental pollution caused by themselves in turn inhibits their output performance and long-term beneficial development. The government should focus on implementing differentiated energy-saving strategies to reduce smog and to establish a market-oriented long-term energy-saving mechanism. The government should include smog and other traditional environmental pollutants into the GDP assessment indicators to achieve a balance between smog control and economic development.

3. For enterprises, improving the external environment of employees (such as improving air quality) is conducive to reducing medical accidents. Air quality improvement helps to increase the enthusiasm of employees, especially for promoting the substantial innovation output of the company, which enhances the company's long-term and sustainable competitiveness. In addition to the pursuit of improving their economic benefits, enterprises should also consider possible environmental pollution problems. Therefore, enterprises should pay attention to technological innovation and reduce the traditional production methods of high energy consumption, high pollution, and low output. If every company targets to improve the environmental pollution caused by its own output, then it can create a better working and living environment and promote the economy's healthy development.

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