

## Research Article

# Applying Meta-Frontier Approaches to Profitability Estimation: In Case of the Effects of Official Independent Directors

Xiaozhi Xu <sup>1</sup>, Lichen Chou <sup>2</sup>, Qing Lu <sup>3</sup> and Yaqi Tian <sup>4</sup>

<sup>1</sup>School of Finance and Trade, Wenzhou Business College, Wenzhou, China

<sup>2</sup>Business School, Shantou University, Shantou, China

<sup>3</sup>School of Economics and Trade Management, Wenzhou Vocational College of Science and Technology, Wenzhou, China

<sup>4</sup>Department of Diplomacy and Foreign Affairs Management, China Foreign Affairs University, Beijing, China

Correspondence should be addressed to Qing Lu; [luqing@wzvcst.edu.cn](mailto:luqing@wzvcst.edu.cn)

Received 23 May 2022; Revised 19 June 2022; Accepted 14 July 2022; Published 8 August 2022

Academic Editor: Amandeep Kaur

Copyright © 2022 Xiaozhi Xu et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The meta-frontier approach can mathematically understand the production dynamics. With the help of meta-frontier approach differences, the efficiency of income and earnings between companies with different structure can be estimated. Considering the great influence of independent directors on the economic market, this study estimated such effects from the perspective of production function models. It is found that the revenue efficiency results can be optimized without considering the technology heterogeneity for listed companies. When considering the common production boundary, there is an issue that the revenue efficiency of listed companies that own official independent directors is lower than other listed companies that without official independent directors, and the empirical results show that the withdrawal of official independent directors in the market has a positive impact on the profitability of the company.

## 1. Introduction

The board of directors is an important part in the company's investment decision-making and execution process, and independent directors play an important role in relieving agency conflicts and protecting the interests of small and medium investors [1, 2]. Previous literature suggested that the company's directorship mechanism could fully exert its functions such as supervisory, strengthening, and supporting operational resources [3, 4]. In the study of officials as independent directors, domestic literature pointed out that listed companies could establish good interoperability with the government by hiring government officials to enter the board of directors and obtain more resources, policy support, and projects. Lu et al. [5] pointed out that the appointments of government and university officials as independent directors are obviously different in terms of business operation violations. The violation of the former is significantly higher than the latter. The author believed that the relevant provisions of the central organization

department were conducive to the maintenance and development of the market order [6–8].

The differences in the operating patterns of listed companies not only reflect the difference in management culture but also cause differences in the marketing targets required in the operation process; thus, the input structure of the company's revenue, manpower, or capital investment would be influenced [9–11]. However, previous literature on the operational efficiency of enterprises mostly used the stochastic boundary method of Battese and Coelli [12] or extended the data-envelope analysis method proposed by Charnes et al. [13] to explore the impact of different management types on operating efficiency. These researchers use different management patterns as exogenous environmental variables to explore their impact on operating efficiency or estimate a representative production boundary and calculate the operating (technical) efficiency of each sample hotel and make comparison between each group's different management patterns [14, 15]. However, both of these approaches ignore the issue of using

heterogeneous production technologies for different types of management. Different types of managers in the same industry may have different production behaviors and technologies due to differences in organizational structure, structure of operating directors, or input factor attributes [16, 17]. Under such circumstances, if the performance assessment is still conducted by using the homogeneous assumption of traditional production techniques, the estimation results may be biased or miscalculated. If companies consider the heterogeneity of production techniques in each group and individually estimate the production boundaries of each group, then they compare the performance of cross-group operations and would lose their economic significance due to differences in the baseline (production boundary).

This study therefore takes China's listed companies of the textile industry as a case and discusses the effect of official independent directors on the profitability of listed companies. Based on the perspective of production performance, the author uses the performance model to analyze the differences in the operating efficiency and income efficiency between companies with official independent directors and other companies. Since the regulation limiting official independent director was not actually implemented until 2015, the author therefore empirically collects the panel data of six years from 2010 to 2015 for research. The characteristics of this study are as follows: (1) under the requirements of the comparison of technical heterogeneity and efficiency, the author uses the meta-frontier model proposed by Battese et al. [18] and O'Donnell et al. [19] to divide the samples into groups such as companies with official independent directors and companies without official independent directors according to different management patterns. The meta-frontier model is adopted because this study was inspired by the work of Walheer et al. [20] in European Journal of Operational Research. The methodological reflections will be explained in the next section. Based on the baseline of the overall industry, the differences in the operating efficiency and profit earning efficiency of different directors' structure types are compared. (2) This study also quotes a stochastic boundary model proposed by Battese and Coelli [12], which includes location (such as whether the enterprise is located in the municipality), market characteristics (market competition degree), individual enterprise characteristics (operating year), and the effect of exogenous environment variables on operation and earnings efficiency.

## 2. Reflections on Estimation Methodologies

The concept of co-production boundary was first proposed by Hayami [21] and Hayami and Ruttan [22]. Hayami and Ruttan [22] thought that the common production function could be regarded as the envelope of the classical production function. Ruttan et al. [23] defined the common production function as the envelope formed by the most efficient production sites among the groups. This innovative concept provided a more appropriate basis for further analysis and reduced the misgivings of comparative analysis errors between groups [24–26]. Then, Lau and Yotopoulos [27], and

Kim and Lau [28] applied and conducted empirical analysis of cross-country data. Besides, Gunaratne and Leung [28] and their followers such as Kovalevsky and Máñez-Costa [30] added random concepts to common production functions.

Battese and Rao [31] proposed the random co-production boundary model and used the SFA method to estimate the technical efficiency of cross-group comparisons and no longer used the methods proposed in the previous literature [27]. He first converted the factors of each group into a certain proportion, then deleted the individual differences between the conversion factors of each group by means of differentials, and concluded that the conversion factor could not be estimated. Battese et al. [18] modified the model of Battese and Rao [31], assuming that there was only one data-generation process, and proposed a two-stage method for estimating common boundary parameters. In the first stage, the SFA method was used to estimate the production boundary and technical efficiency for each group. In the second stage, the parameters obtained from the first stage were estimated and the data of each group were merged. The linear programming (LP) and the quadratic programming (QP) were used to estimate the common production boundary and technology. The technology gap ratio (TGR) could be used to solve the problem that the common production boundary could not envelop the production boundaries of all groups, and a cross group comparison could also be made.

O'Donnell et al. [19] used the concept of distance function to establish the theoretical framework of the joint production boundary, group boundary, and the relationship between the two more clearly. At the same time, the DEA method and the SFA method were used to estimate the common production boundary. Between 1986 and 1990, the agricultural production data of 97 countries were divided into four groups according to regions, and the technical efficiency of each group was compared. Since Battese et al. [18] and O'Donnell et al. [19] proposed a two-stage method for estimating common production functions, the development of the common production function has matured. At present, most scholars entitled such SFA also as "meta-frontier analysis." Recently, many scholars have paid attention to it and applied it to empirical research. For example, Shen et al. [32], Luo et al. [33], Nakaishi et al. [34], Chou et al. [35], and Chou and Zhang [39] have successful applications. Similar to these literature, this study uses meta-frontier analysis as an exploratory tool for further estimation in case of the textile industry.

## 3. Methodology: Meta-Frontier Analysis

Assuming that there are  $J (>1)$  groups, the  $i$ th manufacturer of the  $j$ th group uses  $N$  kinds of inputs,  $x = (x_1, \dots, x_N)$ , produces  $M$  kinds of outputs,  $y = (y_1, \dots, y_M)$ , and the production technology is of strong disposability. The production technology of  $j$ th group could be expressed as follows:

$$T^j = \{(x, y): x \geq 0; y \geq 0; x \text{ can be used by firms in group } j \text{ to produce } y\} \quad (1)$$

According to the production technology  $T$ , the input requirement set of the  $j$ th group and the input surface distance function are, respectively, defined as follows:

$$L^j(y) = \{x: (x, y) \in T^j\}, j = 1, 2, \dots, J; \text{ and,} \quad (2)$$

$$D_I^j(x, y) = \sup_{\lambda} \left\{ \lambda > 0: \frac{x}{\lambda} \in L^j(y) \right\} j = 1, 2, \dots, J. \quad (3)$$

According to Färe and Primont [37], the input surface distance function satisfies the normal conditions such as nondecreasing, convexity, and linear homogeneous for the factor input vector  $x$ . Therefore, the input distance function could be expressed as the reciprocal of the technical efficiency of the input surface defined by Farrell [38]. That is,

$$0 \leq \frac{1}{D_I^j(x, y)} = TE_I^j(x_t, y_t) \leq 1. \quad (4)$$

According to Battese et al. [18] and O'Donnell et al. [19], all the manufacturers with the basic concepts of the common production boundary have the potential opportunities to use the common boundary technology, but the manufacturers of the groups will be faced with different production environments, such as the production resources, the relative input price, and the overall economic environment. The function of selecting different production technologies for production and using the common boundary technology for production is a meta-frontier production function, which could be regarded as the envelope curve of the production function of each group. In other words, meta-technology could be considered as the convex hull of each group's technical boundary [19], which is defined as follows:

$$T^* \equiv \text{convex hull}\{T^1 \cup T^2 \cup \dots \cup T^J\}. \quad (5)$$

Therefore, according to O'Donnell et al. [19], the meta-technology set can be expressed as follows:

$$T^* = (x, y): x \geq 0; y \geq 0; x \text{ can produce } y \text{ in at least one group's technology, } T^1 \cup T^2 \cup \dots \cup T^J. \quad (6)$$

According to the common border production technology  $T^*$ , the input set of the common boundary and the input meta distance function can be defined as follows:

$$L^*(y) = \{x: (x, y) \in T^*\}, \quad (7)$$

$$D_I^*(x, y) = \sup_{\lambda} \left\{ \lambda > 0: \frac{x}{\lambda} \in L^*(y) \right\}. \quad (8)$$

According to equations (1)–(8), it can be concluded that the common boundary is the boundary of the unrestricted technology set, and the group boundary is the boundary of the restricted technology set. The reason for the limitation is that different groups of vendors face the different production environment. The distance function between the input surface distance function and input surface of any group must satisfy the following relationship:

$$D_I^j(x, y) \leq D_I^*(x, y) \Rightarrow TE_I^*(x, y) \leq TE_I^j(x, y), j = 1, 2, \dots, J. \quad (9)$$

Using formula (9), we can derive the technical gap ratio ( $TGR_I^j$ ) for each group's input surface as follows:

$$0 \leq TGR_I^j(x, y) = \frac{D_I^j(x, y)}{D_I^*(x, y)} = \frac{TE_I^*(x, y)}{TE_I^j(x, y)} \leq 1. \quad (10)$$

The value should be between 0 and 1, which represents the ratio of the potential output of the  $j$ th group's production boundary output relative to the common production boundary. The larger the  $TGR_I^j$  value, the closer the production boundary of the  $j$ th group is to the common production boundary, and the smaller the value is, the further

the  $j$ th group production boundary is from the common production boundary.

Finally, using formula (10), the input surface can be used to produce the boundary. The technical efficiency  $TE_I^*$  is decomposed as follows:

$$TE_I^*(x, y) = TE_I^j(x, y) \times TGR_I^j(x, y). \quad (11)$$

In this study, the two-stage common distance function estimation step is used. In the first stage, the stochastic boundary model of Battese and Coelli [12] is used to consider the influence of the exogenous environmental variables on the technical efficiency, and the most approximate method is used to estimate the parameter vector of the input surface distance function in each group and calculate each vendor's technical efficiency estimate ( $TE_{it}^j$ ).

In the second stage, the author uses the linear programming (LP) and quadratic programming (QP) proposed by Battese et al. [18] to estimate the parameters of the common distance function parameters of the input surface. Special attention should be paid to the fact that both of the above estimation methods must be solved through mathematical programming methods. The estimated standard error of the parameter estimation formula is obtained by Battese et al. [18] by using the simulation or bootstrap method. Estimation of the  $TE_{it}^*$  value from the parameter estimates is obtained in the second stage, together with the estimate  $TE_{it}^j$  obtained in the first stage, and an estimate of  $TE_{it}^j$  could be obtained by using equation (11).

According to Chen et al. [39], the detail description is as follows:

TABLE 1: Variable definitions.

Variable attribute	Variate	Definition
Output variable	$Y$	Annual operating income of listed textile enterprises (RMB million)
Input variable	$L$	Total input labor force (thousand people)
	$K$	Total investment in fixed assets, intangible assets and other long-term assets (RMB million)
Director	GOV	Official independent director employed by listed company in current year = 1
	HHI	Market concentration
Environment variables	AGE	Business year (year)
	CITY	Company located in a municipality = 1
	COASTAL	Company located in a coastal province = 1

- (1) Minimum sum of absolute deviations, which is also known as linear programming (LP), is used to solve the optimization problem:

$$\text{Min}L \equiv \sum_{i=1}^N \sum_{t=1}^T \left| \ln f(X_{it}, \beta^*) - \ln f(X_{it}, \widehat{\beta}_{(j)}) \right|. \quad (12)$$

$$s.t. \ln f(X_{it}, \beta^*) \geq \ln f(X_{it}, \widehat{\beta}_{(j)}). \quad (13)$$

If the production function is log linear, then the target function can be simplified as follows:

$$\text{Min}L \equiv \sum_{i=1}^N \sum_{t=1}^T (X_{it}\beta^* - X_{it}\widehat{\beta}_{(j)}), \quad s.t. X_{it}\beta^* \geq X_{it}\widehat{\beta}_{(j)}. \quad (14)$$

Since each individual group's estimated parameter value is  $\widehat{\beta}_{(j)}$ ,  $j = 1, \dots, R$ , in the minimization process which is assumed to have a fixed value, this LP problem is equivalent to the minimized target function  $L^* \equiv \overline{X}\beta^*$ , where  $\overline{X}$  denotes the average vector of all variables.

- (2) Minimum sum of squares of deviations, which also known as the quadratic programming method (QP), is used to solve the optimization problem as follows:

$$\text{Min}LL \equiv \sum_{i=1}^N \sum_{t=1}^T (X_{it}\beta^* - X_{it}\widehat{\beta}_{(j)})^2, \quad s.t. X_{it}\beta^* \geq X_{it}\widehat{\beta}_{(j)}. \quad (15)$$

This estimation method is equivalent to the restricted least squares method. The whole calculation process is carried out through STATA 17.

#### 4. Results and Discussion

This study applies the CSMAR database and selects samples of private China's listed energy companies in textile industry from 2010 to 2015. The CSMAR database is currently the largest in China and contains comprehensive economic and financial research databases. The database includes China's corporate stocks, companies, funds, bonds, derivatives, economy, industry, currency markets, overseas, sectors, information and technology, finance, special topics, and many other economic indicators. It is important to note that Content and Format Standard of Company Information

Disclosure of Public Offering Securities No. 2 "Annual Report Content and Format" announced by the China Securities Regulatory Commission (CSRC) in December 2007 explicitly requires companies listed in China, which should be published in 2007 and in the following years to disclose a summary report on the performance of the board of auditors set up by the board of directors. Therefore, we can check the changes of directors' structure in listed companies in subsequent years. In the study sample selection, after excluding the missing data and nonaccounting firm independent executive sample, we get a total of 254 calculations. In terms of variable setting, we consider whether the official director (GOV) is employed in that year, business income of the current year ( $Y$ ), total input labor ( $L$ ), total investment ( $K$ ) in purchasing and building fixed assets, intangible assets, and other long-term assets. In addition, environmental variables such as location variables (whether the company is located in a municipality or a coastal province), market concentration (HHI), and business operating time (AGE) are considered. The specific variables are listed in Table 1. Among them, the author uses the variable GOV director status as a group of companies to analyze and compare whether there is a clear difference in the efficiency of the common border between listed companies with official independent directors and those companies without official independent directors.

The empirical model is set as follows:

$$\ln l = \ln D_l(y_{it}, x_{it}, t; \beta) + v_{it} - u_{it}. \quad (16)$$

Among them,  $y_{it}$  is the  $t$ th operating income of the  $i$ th company,  $x_{it}$  is the  $t$ th factor input variable of the  $i$ th enterprise (total investment labor and total asset investment),  $\beta$  is the vector to be estimated,  $v_{it}$  is the random interference item, which is the same and independent normal random variable,  $u_{it}$  represents the technical inefficiency term, a non-negative random variable, and  $v_{it}$  and  $u_{it}$  are assumed to be statistically independent. Table 2 summarizes the results of the first-stage random boundary estimation. The empirical results show that all variables except the variable AGE (business year) have a statistically significant level. Among them, the empirical results show that the input variables of the company's production process have a significant positive impact on its revenue. In the estimation of environmental variables, the results show that the variables HHI, CITY, and COASTAL all have positive effects and have statistically significant effects, indicating that the higher the market concentration, the higher the company's revenue. In addition, when the company is located in a municipality directly

TABLE 2: Random boundary estimation of the first stage.

Variable	Company with official independent director (GOV) operating income logarithm ln (Y)		Company with no official independent director (GOV) operating income logarithm ln (Y)	
	Coefficient value	Standard error	Coefficient value	Standard error
Constant term	2.534***	0.306	-2.548***	0.288
ln(L)	0.406*	0.061	1.662***	0.345
ln(K)	1.884**	0.950	2.545***	0.603
ln(L) × ln(K)	-2.571***	0.551	0.450	0.961
Environment variables				
Constant term	3.567***	1.554	5.202***	1.325
HHI	1.555***	0.566	2.551***	0.614
AGE	0.021	0.088	0.028	0.045
CITY	2.423***	0.457	2.811***	0.181
COASTAL	0.450**	0.230	0.451**	0.200
$\sigma_u^2 + \sigma_v^2$	0.088***	0.022***	0.022***	0.008
$\sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$	0.819***	0.022	0.988***	0.028
Log-likelihood	273.800		364.340	
n		117		137

Data source: CSMAR database. Note: \*\*\*, \*\*, \* indicates statistical significance at the level of confidence of 1%, 5%, and 10%, respectively.

TABLE 3: Estimation for pool-SFA and QP methods.

Variable	Pool-SFA		QP model	
	Estimated value	Standard error	Estimated value	Standard error
Constant term	2.516	0.791	7.340	5.376
ln(L)	3.789	1.473	3.330	1.912
ln(K)	0.005	0.519	-2.272	0.866
ln(L) × ln(K)	2.516	0.791	7.340	5.376

Note. (1) Estimated standard errors of QP are estimated by using bootstrapping. (2) The pool-SFA model does not list the estimated value of  $\sigma_u^2$  and  $\sigma_v^2$ .

under the central government or in a coastal province, it indicates that companies in the relatively developed regions with economic development also have a positive impact on their revenue.

Based on the quadratic programming (QP) method proposed by Battese et al. [17], Table 3 shows the estimation results. To be more specific, we applied the random boundary distance function shown in formula (12). It could be found that there are some differences between the traditional random boundary model (pool-SFA, in which pool means multiple cross-sectional data were merged) and the QR estimation results, but the basic effect of input variables on output variables is consistent with the results in Table 2. The main reason for the differences between the two is that the pool-SFA method combines the group data of different boards of directors together and directly estimates the random boundary distance function while neglecting the different management and the heterogeneity of the production technology. The two-order programming rule applies the mathematical programming to estimate the common production function relationship. In addition, the use of the QP model system assumes that there are differences in the operating revenue performance of a listed food company with an official independent director and a company without official independent director. The author uses the likelihood-ratio (LR) test and the null hypothesis to assume that the production boundaries of the two types of firms are the same, and the LR verification statistic  $\lambda =$

$-2\{\ln(H_0) - \ln(H_1)\}$  is used for estimation. Among them,  $\ln(H_0)$  is the log-likelihood function value obtained by merging and accumulating the estimated values of all the group samples, and  $\ln(H_1)$  is the sum of the values of the individual random boundary logarithm probabilistic functions for each group. The LR test statistic is 181.080. It rejects the null hypothesis. It means that there is indeed heterogeneity among the independent directors and nonexistent officials of the listed food companies. It is appropriate to use the common boundary function to analyze and compare the production efficiency and profit performance of different groups.

Table 4 lists the related technical efficiency estimated value under the common production boundary of the group. The size of the TGR reflects the difference in the manufacturer's level of production technology. The greater the TGR value, the closer the technical level used by the manufacturer is to the common boundary technology. Bos et al. [40] analyzed the banking industry competition and pointed out that the TGR value and the market competition presented a U-shaped curve. It represented that as the degree of competition increases, manufacturers' production behavior would gradually shift to the production of high-quality and specialized products. From this table, it can be found that without considering the technical heterogeneity, there is an efficiency gain (the average efficiency is 0.865) for the listed company with official independent directors over the other companies (the average efficiency is 0.831).

TABLE 4: Profitability of listed companies.

	Mean	Variance	QP model	
			Min	Max
Listed company with official independent director (GOV)				
Technological gap (TGR)	0.786	0.116	0.499	1.000
Random boundaries of the first stage (TE)	0.865	0.078	0.599	0.945
TE*	0.714	0.118	0.372	0.942
Listed company with no official independent director (NO-GOV)				
Technological gap (TGR)	0.844	0.081	0.519	1.000
Random boundaries of the first stage (TE)	0.831	0.090	0.552	0.943
Common border efficiency (TE*)	0.739	0.106	0.410	0.927
Whole sample				
Technological gap (TGR)	0.800	0.102	0.405	0.950
Random boundaries of the first stage (TE)	0.834	0.082	0.552	0.945
Common border efficiency (TE*)	0.703	0.112	0.351	0.942

TABLE 5: Average common boundary efficiency and technical gap for each group.

Year	Listed company with official independent director (GOV)			Listed company without official independent director (NO-GOV)		
	TE	TGR	TE*	TE	TGR	TE*
2010	0.791	0.700	0.604	0.834	0.765	0.670
2011	0.851	0.945	0.793	0.822	0.884	0.766
2012	0.806	0.899	0.831	0.849	0.783	0.735
2013	0.842	0.819	0.700	0.819	0.848	0.748
2014	0.894	0.815	0.694	0.820	0.859	0.748
2015	0.857	0.699	0.652	0.775	0.869	0.725

However, when considering the common production boundary, the TGR value of listed company with official independent director is less than other companies, and the production activity level of listed company with official independent director is farther from the common technology boundary than the other. When considering the common production boundary, the earnings performance (the average efficiency is 0.714) of listed company with official independent director is lower than listed company without official independent director (the average efficiency is 0.739).

Table 5 further lists the average common boundary efficiency and technical gaps for different groups over the years. It can be found that when considering the common border efficiency and technical gap, the earnings performance (TE\*) of listed company with official independent director (GOV) is lower than that of listed company without official independent director (except for the year of 2009 and 2010). As for the reasons for the differences in earnings performance among groups, Ye et al. [41] and Lu and Yang [5] believed that in a transitional economy such as China with weak property rights protection and high government intervention, listed companies that appointed government officials to enter the board of directors and established a good relationship with the government could obtain more critical resources and policy support, and this might also induce listed companies to seek rent-seeking space. This situation shows that companies that hire official independent directors may invest other capital in the business

process in the nonproduction investment and nontechnical upgrading. That may indirectly cause waste of input resources and bring about negative influence on the company's own production efficiency and profitability.

## 5. Conclusion

This study uses the CSMAR database to examine the operating data of listed companies in textile industry from 2010 to 2015 and analyzes the effect of official independent directors on the profitability of listed companies. By using the empirical model, this study uses the common boundary performance model to analyze the differences in the operating efficiency and income efficiency between companies with official independent director and the others. The empirical evidence shows that under the condition of not considering technological heterogeneity, there is a higher efficiency of the earnings of listed companies with official independent directors than other companies. However, when considering the common production boundary, there is an issue that the earnings performance of listed companies with official independent directors is lower than other companies; the research results show that the withdrawal of the official independent directors in the market has a positive impact on the profitability of the company. This article believes that the poor performance of earnings of listed companies with official independent directors may be caused by the fact that other capitals in the business process are invested in nonproduction and nontechnical upgrading,

indirectly leading to waste of input resources, and negatively affecting the company's own production efficiency and profitability.

To sum up, the announcement of the Chinese government's Opinions on Further Stipulating the Issue of Party and Government Cadres Working in Enterprises and Notice of the General Office of the Ministry of Education on Conducting a Special Inspection of Party and Government Leading Cadres Part-time in the Enterprise has cut off companies' channels of building political relations with governments by hiring government officials to serve as independent directors, reducing the potential for capital to invest in nonproduction inputs and nontechnical upgrades. This not only helps maintain the market order but also has a substantial positive impact on the development of industrial competition. Looking at the changing trend of China's economy and industry, the professionalization and specialization of independent directors and the professional competence of independent directors should be regarded as the current major development goals. In addition, this study focuses more on using meta frontier to show the regulatory changes in China, but there are still many limitations in this research. First of all, due to the lack of data, we cannot discuss the situation 10 years ago, so we did not cover it. In addition, we are looking at one industry and therefore may need to compare with other industries simultaneously in the future. Meanwhile, future research directions of our work may include cases from other developing countries.

### Data Availability

The datasets used during the current study are available from the corresponding author upon reasonable request.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

### Authors' Contributions

Xiaozhi Xu and Lichen Chou performed conceptualization and formal analysis and developed the methodology and wrote the original draft. Qing Lu performed conceptualization, wrote the final draft, and performed the supervision. Yaqi Tian collected data and performed the final draft editing.

### References

- [1] E. F. Fama and M. C. Jensen, "Separation of ownership and control," *The Journal of Law and Economics*, vol. 26, no. 2, pp. 301–325, 1983.
- [2] R. B. Adams, B. E. Hermalin, and M. S. Weisbach, "The role of boards of directors in corporate governance: a conceptual framework and survey," *Journal of Economic Literature*, vol. 48, no. 1, pp. 58–107, 2010.
- [3] D. L. Delano and J. D. Knottnerus, "The Khmer Rouge, ritual and control," *Asian Journal of Social Science*, vol. 46, no. 1–2, pp. 79–110, 2018.
- [4] E. Gerharz and J. Pfaff-Czarnecka, "Spaces of violence in south asian democracies," *Asian Journal of Social Science*, vol. 45, no. 6, pp. 613–638, 2017.
- [5] D. Lu and D. Yang, "Independent directors' official background and corporate fraud," *Accounting Research*, vol. 8, pp. 55–61, 2017.
- [6] H. Fu and X. Liu, "Research on the phenomenon of Chinese residents' spiritual contagion for the reuse of recycled water based on SC-iat," *Water*, vol. 9, no. 11, p. 846, 2017.
- [7] Z. Liu, "Teaching reform of business statistics in college and university," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 13, no. 10, pp. 6901–6907, 2017.
- [8] A. M. Yang, Y. Han, S. S. Li, H. W. Xing, Y. H. Pan, and W. X. Liu, "Synthesis and comparison of photocatalytic properties for bi2wo6 nanofibers and hierarchical microspheres," *Journal of Alloys and Compounds*, vol. 695, pp. 915–921, 2017.
- [9] M. V. Achim, S. N. Borlea, and A. M. Anghelina, "The impact of fiscal policies on corruption: a panel analysis," *South African Journal of Economic and Management Sciences*, vol. 21, no. 1, pp. 1–9, 2018.
- [10] M. Altwaiji, "History of Saudi folklore and factors that shaped it," *Trames. Journal of the Humanities and Social Sciences*, vol. 21, no. 2, p. 161, 2017.
- [11] D. Fagan, "Activist archive: youth culture and the political past in Indonesia, written by doreen lee," *Asian Journal of Social Science*, vol. 46, no. 1–2, pp. 208–210, 2018.
- [12] G. E. Battese and T. J. Coelli, "A model for technical inefficiency effects in a stochastic Frontier production function for panel data," *Empirical Economics*, vol. 20, no. 2, pp. 325–332, 1995.
- [13] A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the efficiency of decision making units," *European Journal of Operational Research*, vol. 2, no. 6, pp. 429–444, 1978.
- [14] A. Ahmed, "The philosophy of nuclear proliferation/non-proliferation: why states build or forgo nuclear weapons?" *Trames. Journal of the Humanities and Social Sciences*, vol. 21, no. 4, p. 371, 2017.
- [15] K. Anniste, L. Pukkonen, and T. Paas, "Towards incomplete migration: Estonian migration to Finland," *Trames. Journal of the Humanities and Social Sciences*, vol. 21, no. 2, p. 97, 2017.
- [16] J. Gans and M. D. Ryall, "Value capture theory: a strategic management review," *Strategic Management Journal*, vol. 38, no. 1, pp. 17–41, 2017.
- [17] H. J. Kim and B. K. Kim, "Risk-based perspective on the choice of alliance governance in high-tech industries," *Journal of Management and Organization*, vol. 23, no. 5, pp. 671–688, 2017.
- [18] G. E. Battese, D. S. P. Rao, and C. J. O'Donnell, "A meta-frontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies," *Journal of Productivity Analysis*, vol. 21, no. 1, pp. 91–103, 2004.
- [19] C. J. O'Donnell, D. S. P. Rao, and G. E. Battese, "Metafrontier frameworks for the study of firm-level efficiencies and technology ratios," *Empirical Economics*, vol. 34, no. 2, pp. 231–255, 2008.
- [20] B. Walheer, "Meta-frontier and technology switchers: a nonparametric approach," *European Journal of Operational Research*, 2022.
- [21] Y. Hayami and V. W. Ruttan, *Agricultural Productivity Differences Among Countries*, pp. 895–911, The American economic review, United States, 1970.

- [22] Y. Hayami and V. W. Ruttan, *Agricultural Development: An International Perspective*, The Johns Hopkins Press, Baltimore, Md/London, 1971.
- [23] V. W. Ruttan, H. P. Binswanger, Y. Hayami, W. W. Wade, and A. Weber, "Factor Productivity and Growth: A Historical Interpretation," *Induced Innovation: Technology institution, and developments*, vol. 12, pp. 44–90, 1978.
- [24] X. Zhao, X. Ma, Y. Shang, Z. Yang, and U. Shahzad, "Green economic growth and its inherent driving factors in Chinese cities: based on the Metafrontier-global-SBM super-efficiency DEA model," *Gondwana Research*, vol. 106, pp. 315–328, 2022.
- [25] N. Shen, H. Liao, R. Deng, and Q. Wang, "Different types of environmental regulations and the heterogeneous influence on the environmental total factor productivity: empirical analysis of China's industry," *Journal of Cleaner Production*, vol. 211, pp. 171–184, 2019.
- [26] G. Pu, Y. Zhang, and L. C. Chou, "Estimating financial information asymmetry in real estate transactions in China - an application of two-tier Frontier model," *Information Processing & Management*, vol. 59, no. 2, Article ID 102860, 2022.
- [27] L. J. Lau and P. A. Yotopoulos, "The meta-production function approach to technological change in world agriculture," *Journal of Development Economics*, vol. 31, no. 2, pp. 241–269, 1989.
- [28] J. I. Kim and L. J. Lau, "The sources of economic growth of the East Asian newly industrialized countries," *Journal of the Japanese and International Economies*, vol. 8, no. 3, pp. 235–271, 1994.
- [29] L. H. P. Gunaratne, "Asian black tiger shrimp industry: a productivity analysis," in *Chapter 5 in Economics and Management of Shrimp and Carp Farming in Asia: A Collection of Research Papers Based on the ADB/NACA Farm Performance Survey*, P. S. Leung and K. R. Sharma, Eds., p. 240, Network of Aquaculture Centers in Asia-Pacific (NACA), Bangkok, 2001.
- [30] D. V. Kovalevsky and M. Máñez-Costa, "Dynamics of water-constrained economies affected by climate change: nonlinear and stochastic effects," *Mathematical Topics on Modelling Complex Systems*, vol. 1, pp. 105–129, 2022.
- [31] G. E. Battese and D. P. Rao, "Technology gap, efficiency, and a stochastic metafrontier function," *International Journal of Business and Economics*, vol. 1, no. 2, p. 87, 2002.
- [32] Z. Shen, K. Bai, T. Hong, and T. Balezentis, "Evaluation of carbon shadow price within a non-parametric meta-frontier framework: the case of OECD, ASEAN and BRICS," *Applied Energy*, vol. 299, Article ID 117275, 2021.
- [33] Y. Luo, Z. Lu, S. Muhammad, and H. Yang, "The heterogeneous effects of different technological innovations on eco-efficiency: evidence from 30 China's provinces," *Ecological Indicators*, vol. 127, Article ID 107802, 2021.
- [34] T. Nakaishi, H. Takayabu, and S. Eguchi, "Environmental efficiency analysis of China's coal-fired power plants considering heterogeneity in power generation company groups," *Energy Economics*, vol. 102, Article ID 105511, 2021.
- [35] L. C. Chou, W. H. Zhang, M. Y. Wang, and F. M. Yang, "The influence of democracy on emissions and energy efficiency in America: new evidence from quantile regression analysis," *Energy & Environment*, vol. 31, no. 8, pp. 1318–1334, 2020.
- [36] L. C. Chou and W. H. Zhang, "The effect of democracy on energy efficiency in European countries," *Economic Research-Ekonomska Istraživanja*, vol. 33, no. 1, pp. 3476–3491, 2020.
- [37] R. Färe and D. Primont, "Distance functions. In Multi-Output Production and Duality: Theory and Applications," pp. 7–41, Springer, Dordrecht, Netherlands, 1995.
- [38] M. J. Farrell, "The measurement of productive efficiency," *Journal of the Royal Statistical Society: Series A (General)*, vol. 120, no. 3, pp. 253–281, 1957.
- [39] C. Y. Chen, S. H. Lin, L. C. Chou, and K. D. Chen, "A comparative study of production efficiency in coastal region and non-coastal region in Mainland China: an application of Metafrontier model," *Journal of International Trade & Economic Development*, vol. 27, no. 8, pp. 901–916, 2018.
- [40] J. W. Bos, J. W. Kolary, and R. V. Lamoen, *Competition and Innovation: Evidence from Financial Services*, Working paper, China, 2009.
- [41] Q. Ye, L. Y. Zhao, and S. C. Liu, "A study of politician-to-firm revolving door of independent directors: evidence from a natural experiment," *Economic Research Journal*, vol. 6, pp. 98–113, 2016.