Received: April 19, 2025; **Accepted:** October 30, 2025; **Published:** January 1, 2026.
DOI. 10.30473/coam.2025.74337.1302
Volume 11, Issue 1, p.p. 153-198: Winter-Spring (2026)
Research Article

Open Access

Control and Optimization in Applied Mathematics - COAM

Efficiency Analysis of Technology-Based Firms Using the SBM-DEA Model: Evidence from Iran

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How to Cite
Mohammadhshemi, Z., Ghorbani-Moghadam, Kh., Allahy, S., Ghazinoory, S. (2026). "Efficiency analysis of technology-based firms using the SBM-DEA model: Evidence from Iran", Control and Optimization in Applied Mathematics, 11(1): 153-198, doi: 10.30473/coam.2025.74337.1302.

Abstract. This study employs a two-stage analytical framework to assess efficiency, comprising a standard SBM evaluation and a novel weighted SBM model. Unlike conventional SBM-DEA applications, the proposed weighted model uses an enhanced slack-based mechanism that prioritizes strategic inputs (RD investment, number of employees, and funding) and clearly distinguishes input redundancies (e.g., excessive RD expenditure or staffing) from output deficiencies (e.g., weak revenue performance). This separation yields more precise and targeted diagnostic insights. Additionally, the model incorporates sector-specific efficiency differentiation, supported by ANOVA, enabling assessment of cross-firm inefficiencies and their statistical significance in terms of systemic versus sector-specific phenomena. The methodology is applied to a distinctive panel of 146 technology-based firms (TBFs) in Iranian science and technology parks from 2021–2023, a context rarely explored with DEA in emerging markets. The study combines quantitative DEA results from both models with qualitative follow-up analyses of factors such as marketing strategies, private investment initiatives, and certification achievements, producing a robust mixed-methods approach and actionable policy recommendations. A comparative analysis reveals that fully efficient firms comprise 2.7% under the unweighted model and 3.4% under the weighted model, indicating that weighting yields a small, non-significant change in overall efficiency. About 97.3% of firms display efficiency gaps due to input redundancies or output shortfalls. Sectoral tests show no statistically significant inter-sector differences, pointing to systemic inefficiencies across industries. Qualitative insights identify firm-level success factors—effective marketing, certification, and investment strategies—that align with the detected inefficiency patterns. Collectively, these findings offer measurable strategies for improvement, such as reducing redundant investment and enhancing revenue-generation mechanisms, to inform evidence-based policy aimed at the commercialization and growth of TBFs in emerging markets.

Keywords. Data envelopment analysis, Slack-based measure, Efficiency ranking, Sector-specific efficiency, Technology-based firms.

MSC. 90C05; 90C90.

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1 Introduction

Governments across the globe design policies and allocate resources to promote economic development driven by technology, innovation, creativity, and disruption. Technology-based firms (TBFs) are central to dynamic economies, offering new, improved, and modern employment opportunities (Marwick [29]). However, their definitions tend to focus on a constellation of characteristics including firm size, informality, growth rates, operational complexity, absence of a finalized product, and types of financing (Cockayne [11]).

The significance of technological advancement in global development is unquestionable. Consequently, governments are increasing their fiscal investments in science and technology annually to enhance productivity in these domains. Nonetheless, achieving technological progress requires the accumulation of skills, knowledge, and infrastructure. Despite notable growth, inefficiencies in investment utilization have garnered societal criticism, as concerns about low returns on technological investments persist [37].

Performance is generally conceptualized as either organizational inputs or outputs or as the ratio between them, commonly expressed as efficiency (Chen, et al. [8]). As such, input-output efficiency is a crucial indicator in technology development. Benchmarking, defined as the systematic comparison of a firm's performance with that of peer organizations that convert similar inputs into comparable outputs, offers a means for relative performance assessment (Bogetoft and Otto [3]). Efficiency and productivity metrics serve as important indicators in evaluating organizational performance, with efficiency reflecting the extent to which actual production approaches the optimal or standard level. When actual output significantly diverges from potential, organizational efficiency diminishes.

The foundational work on performance measurement was initiated by Debreu in [14] and Chipman in [10]. Farrell then advanced the empirical efficiency measurement by proposing a methodology that minimizes inputs while keeping output levels constant, advocating for evaluating performance against industry best practices [18]. Productivity, in turn, is characterized by the rate at which inputs are transformed into outputs and is typically quantified using partial and total productivity indices [22].

A fundamental step in assessing the technological and innovative performance of firms involves identifying and selecting appropriate input and output variables. One of the most practical and widely used techniques in performance evaluation is Data Envelopment Analysis (DEA), a non-parametric mathematical programming approach that facilitates the relative evaluation of homogeneous decision-making units (DMUs) with comparable inputs and outputs. The DEA offers a data-driven, non-parametric framework for evaluating firms that convert multiple inputs into multiple outputs (Cooper, et al. [13]).

DEA approaches are broadly categorized into radial and non-radial approaches. Radial models assume simultaneous proportional changes across all inputs and outputs, whereas non-radial models account for slacks, discrepancies between actual and optimal input/output levels, thus capturing inefficiencies more comprehensively (Charnes et al. [5]). Charnes et al. [6] extended this framework by allowing the recognition of weak efficiencies through combined input-reduction and output-enhancement models. However, these models typically lack a singular measure of overall efficiency.

To address this limitation, Tone [35] introduced the Slacks-Based Measure (SBM) model, which evaluates all inefficiencies—such as input redundancies and output shortfalls—through a single scalar measure. Unlike radial models, SBM explicitly incorporates slack variables, offering a more comprehensive depiction of inefficiency, with desirable properties such as unit invariance and monotonicity (Tone et al. [36]). Enhancing the performance of TBFs is a strategic imperative for establishing competitive advantage, fostering growth, and creating value-added opportunities. Within Iran's policy framework, supporting the commercialization of technology and the development of technological entrepreneurship, particularly within science and technology parks (STPs), is a key priority for the Vice-Presidency for Science and Technology and Knowledge Based Economy Affairs, aligned with efforts to advance a knowledge-based economy.

This study applies the DEA method and the SBM model to evaluate the efficiency of Iranian TBFs. While the SBM-DEA approach is well-established in operational research for measuring relative performance, its novel contribution in this context lies in its application to a unique dataset of firms operating within Iran's STPs, between 2021 and 2023. The research aims to provide empirical insights into how government policies and support mechanisms influence commercialization performance, bridging the gap between efficiency analysis and evidence-based policymaking in emerging innovation ecosystems. Specifically, this research advances the literature by:

1. Demonstrating the application of the SBM-DEA model and weighted SBM-DEA model in the relatively underexplored context of Iranian TBFs.

2. Highlighting the systemic inefficiencies across sectors, contrasting with prior studies primarily focused on sector-specific issues.

3. Offering actionable recommendations to enhance commercialization outcomes, with implications for the case of Iran as a developing economy and emerging innovation ecosystem.

The main research questions addressed in this study are:

1. What is the appropriate DEA model for evaluating the performance of TBFs?

2. What is the current efficiency status of TBFs across different sectors?

3. What are the characteristics of efficiently performing TBFs?

4. Are there statistically significant differences in efficiency among sectors?

5. Finally, what strategies can be recommended to improve the efficiency of Iranian TBFs?

The paper is organized as follows: Section 2 reviews the policies supporting TBF commercialization and surveys relevant empirical studies. Section 3 describes the data, variables, and methodology utilized. Section 4 presents the research findings and addresses research questions. Section 5 discusses the implications of the results, and Finally, Section 6 concludes with key insights and recommendations. The complete numerical results are provided in Appendix.

2 Theoretical Foundations

The program for supporting the commercialization of technology in Iranian TBFs

Science and Technology Parks (STPs) originated in the 2000s in Iran to revitalize and develop regions, foster more industry-academia interaction, enhance high-tech industry sectors, and support startups [32]. Currently, 59 science and technology parks operate in Iran. According to Felsenstien (1994), the primary objective of STPs is to serve as incubators of innovation, promoting the growth and development of New Technology-Based Firms (NTBFs), facilitating the transfer of knowledge and technology from universities to tenant firms, and encouraging the formation of faculty-based spin-offs. Additionally, STPs are envisioned to act as catalyst for regional development by revitalizing urban areas and stimulating economic growth.

Fukugawa [19] identified that NTBFs located within STPs demonstrate a greater likelihood of engaging in collaborative research with research institutes. Analyzing six parks in Japan from 1998 to 2003, Fukugawa highlighted higher levels of research cooperation among on-park NTBFs. Similarly, Lindelof and Lofsten [26] compared NTBFs located within parks to those outside, finding that firms within STPs exhibited stronger communication links with universities and tended to perform better than their off-park counterparts.

The process of developing and commercializing TBFs within industry is inherently complex, influenced by a range of barriers and facilitators, as well as the distinctive characteristics of both the supply and demand sides of technological innovation (Geisler and Torchetti, 2015). Major challenges include a lack of capability, high risks associated with product commercialization, and difficulties in market presentation for startups and TBFs. These obstacles underscore the necessity for targeted governmental intervention.

In response, Iran has implemented a comprehensive program to support the commercialization of technological products developed within TBFs across all STPs. Initiated in 2014, this program involves identifying qualified products with demonstrated technical and economic viability through the parks. Following evaluation by a dedicated commercialization committee, successful applicants are eligible for support in the form of low-interest financing provided via research and technology funds. The process for granting commercialization facilities is illustrated in Figure 1.

2.1 Measuring Efficiency and the DEA

TBFs occupy a central position within the national innovation system owing to their significant influence on technological advancement and economic growth (Maine et al. [28]). These firms are characterized by a highly competitive environment, rapid growth trajectories, and engagement in global market for innovative products and services that leverage cutting-edge technology (Grilo and Santos [20]; Grinstein and Goldman [21]). Despite their economic contribution, several factors may hinder their full potential, chief among these are managerial capacity and market penetration, with entrepreneurs often exhibiting strengths primarily in technological competencies rather than in management or marketing (Grilo and Santos [20]). Consequently, the success of NTBFs largely hinges on the quality of the management

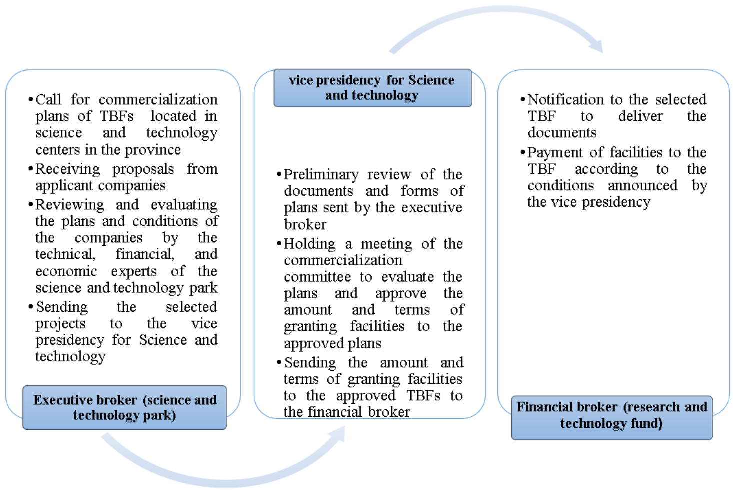

Figure 1: Process of allocation commercialization facilities (Draft Version).

resources, such as access to public funding, R&D Investment (RDI), and workforce size (Rojas and Huergo [31]).

In recent years, the employment of DEA as an assessment tool for evaluating the performance of TBFs has gained prominence, particularly in studies examining innovative firms (Chen et al. [9]; Grilo and Santos [20]; Heng Chen et al. [8], Lu et al. [27]; Sutopo et al. [34]), DEA has also been utilized to analyze factors that influence R&D process efficiency (Chen and Breedlove [7]; Erena et al. [16]; Kim and Shin [25]) (see Table 1). Data Envelopment Analysis (DEA) is a well-established methodology for assessing the efficiency of decision-making units. In complex systems comprising multiple interconnected subsections, Network DEA provides a structured framework for efficiency evaluation (Pourmahmoud et al. [30]). Performance evaluations of NTBFs typically involve similar inputs and outputs variables, with variations often dictated by data availability; this underscores the critical role of R&D activities within these firms. DEA facilitates the identification of inefficiencies at the firm level by benchmark comparison, thereby enabling managers to recognize areas for improvement and implement strategic changes. Importantly, DEA does not offer specific recommendations for corrective actions to improve business performance. Instead, it elucidates the underlying causes of inefficiency, thereby supporting managerial decision-making (Grilo and Santos [20]; Sutopo et al. [34]). For example, Chen et al. [9] examined the application of DEA in assessing the performance of R&D firms in the computer and peripheral equipment sectors within science and technology park incubators. Employing both Charnes, Cooper, and Rhodes (CCR) [5] and Banker, Charnes, and Cooper (BCC) [2] models with three inputs, firm age, R&D capital expenditure, and personnel count, and two outputs, annual sales and patent counts, they observed significant variability in firm performance, despite most firms being technically efficient. Similarly, Chen et al. [9] analyzed six high-tech industries within an STP, using inputs such as personnel, working capital, R&D expenditure, and physical space, and examined outputs like sales and patents over time to assess efficiency and growth trajectories via Malmquist indices. While these studies effectively address key indicators, they often overlook the comprehensive inclusion of output measures and do not consider the influence of firm age, which can be a vital performance determinant.

Grilo and Santos [20], developed a DEA-based framework to help NTBFs within business incubators evaluate and enhance management efficiency. In their case study of Madan Parque in Lisbon, Portugal, inputs included salary costs and R&D investment, while outputs encompassed total sales and product portfolio. Of the 13 incubated units, six were identified as inefficient, implying a need to proportionally increase all outputs according to their efficiency scores. Notably, the analysis revealed that four of these units had disproportionately high R&D expenditures with limited impact on outcomes, indicating opportunities for more resource-efficient R&D investment. However, the study did not account for variables such as firm age or activity diversity, which could provide additional insights. Lu et al. [27] applied DEA to evaluate R&D performance across 194 high-tech firms, considering inputs such as firm assets, R&D spending, staff counts, and number of researchers, and outputs including sales volume, exports, ROI, and patent count. The extensive scope of their sample enhances the robustness of their findings, which aim to assist managers in strategic decision-making to boost R&D effectiveness. Nonetheless, similar to prior studies, their analysis did not incorporate firm age or activity type, factors that could influence performance outcomes. Sutopo et al. [34] constructed a DEA model to assess the efficiency of the university Technology Transfer Office (TTO) incubation process, with a specific focus on accelerating the commercialization of research results. Using an output-oriented Banker et al. [2] model, they evaluated fifteen decision-making units (DMUs) across three stages over five years (2016–2020) at LPIK ITB. Their findings identified eleven efficient and four inefficient DMUs, providing a basis for policy prioritization to enhance university research commercialization. Chen et al. [8] distinguished the stages of technological development and commercialization in China’s high-tech industry. Inputs during the development stage included researcher full-time equivalents (FTEs), internal R&D costs, and facility valuations. Outcomes were assessed through project initiatives, patent filings, and application numbers. The outputs from this phase fed into the subsequent commercialization stage, which evaluated new product sales and export revenues, thereby capturing the transition from R&D to market deployment (Heng Chen et al. [8]).

In Table 1, we summarize the articles discussed in the introduction. Khayatian et al. [24] identified key factors influencing the growth and sustainability of Knowledge-based firms in Iran. Their findings indicated that, in certain cases, the most significant determinants encompassed the fundamental properties of the firm company profile, core business idea, human resources, market dynamics and competition, organizational structure, infrastructure, financial resources, and environmental factors. In a separate study, Amini et al. [1] assessed the efficiency of technology and innovation management within 49 companies, analyzing the underlying causes of inefficiency and proposing strategies for improvement. This evaluation was conducted in two phases: the first focused on enablers, such as essential processes for fostering technological and innovative capabilities, while the second examined the resulting performance and outcomes. The results revealed that although most companies demonstrated high efficiency in the enabler’s stage, a notable proportion were inefficient in producing desired outcomes.

Despite extensive research on various aspects of technology management and innovation in Iran, a comprehensive analysis of the efficiency of technological firms remains lacking. Additionally, this study marks a pioneering effort in applying the SBM-DEA approach to assess the efficiency of technology-based firms and to recommend targeted improvements for enhancing underperforming enterprises.

The literature review highlights that, although numerous studies have employed DEA to evaluate the efficiency of innovative and technology-driven firms, most have relied on the CCR and BCC models. Notably, there is a scarcity of research exploring the efficiency of NTBFs within STPs utilizing a

Table 1: Literature Review (part 1 of 2)

Studies	Journal	Countries	DEA Model	Input Variables	Output Variables	Firms	Sector	Key Findings
(Chen et al., 2004)	International Journal of Business	Taiwan	CCR and BCC models	Firm's age, R&D capital expenditure, and personnel count	Annual sales and number of patents	31	Computers and peripherals firms	Significant variability in R&D performance; identified pathways for inefficient firms to enhance their R&D outcomes.
(Lu et al., 2010)	African Journal of Business Management	Taiwan	CCR and BCC models	Total assets, R&D Expenditure, Total Employees, R&D staff	Number of Patents, Export volume, ROI, Sales revenue	194	High tech firms	Methodology to assess pure technical efficiency, overall technical efficiency, and scale efficiency of high-tech firms.
(Heng Chen et al., 2013)	Information Technology Journal	China	Two-stage DEA	Number of FTE researchers, internal R&D costs, and facility value	New product sales, and export revenue	-	Multiple sub-sectors within high-tech industry	Classification into four levels based on the degree of coordination among high-tech industry sectors.
(Grilo and Santos (2015)	The Scientific World Journal	Portugal	BCC output oriented model	Salary costs and R& D investment	Sales, clients, products	13	New technology-based firms	Inefficient firms tend to over-invest in R&D; firms demonstrated productivity growth during the studied period

Table 1: Literature Review (part 2 of 2)

Studies	Journal	Countries	DEA Model	Input Variables	Output Variables	Firms	Sector	Key Findings
(Miroslav Žižka et al. (2016))	International Journal of Strategic Property Management	Czech Republic	Two-stage DEA, BCC model	Firm age, long-term capital, patents, utility models, trademarks, added value	Patents, industrial designs	1,337	Innovative firms	Notable differences in performance levels, effectiveness, and efficiency across sectors and branches.
Chen and Breedlove (2020)	International Journal of Sports Marketing and Sponsorship	China	Total R&D investment and staffing	R&D expenditure, staff count	Profit, sales revenue, new patents	-	High-tech sports firms	Income tax relief for high-tech enterprises positively impacts both overall innovation efficiency and pure technical efficiency, while government subsidies have a negative effect.
Obsa Teferi Erena, et al. (2021)	Cogent Economics & Finance	Ethiopia	Output-orientation CCR and BCC	Total fixed assets, total employee count	Value-added and operating surplus	43 subsectors	Incubation at various stages	Overall technical efficiency approx. 37%; public-owned subsectors less efficient than private ones.

novel SBM-DEA model. Therefore, this paper proposes an innovative SBM-DEA framework tailored to measure the efficiency of such firms. Also, we contribute to the DEA literature by augmenting the standard SBM model with a diagnostic inefficiency decomposition and a post-hoc mixed-methods analysis. The combination of quantitative efficiency scores, statistical validation via ANOVA, and qualitative insights from benchmarking successful firms provides a comprehensive and actionable understanding of the performance drivers in Iranian technology-based firms, offering significant practical value beyond a theoretical application.

Furthermore, this study distinguishes itself by analyzing the efficiency of companies situated within STPs, using a sufficiently large and homogeneous sample. It also aims to compare results across different types of company activities, offering a nuanced understanding of efficiency variations within this context.

According to the inputs and outputs summarized in Table 1, prior research has employed a variety of variables. Notably, inputs such as the research and development expenditure and personnel numbers have consistently been utilized, alongside outputs like sales and revenue (see Figure 2). Accordingly, this study incorporates three input variables: government funding received, research and development expenditures, and the number of personnel. Additionally, considering data availability from the targeted firms, we include income as an output variable within our SBM-DEA model (see Figure 2).

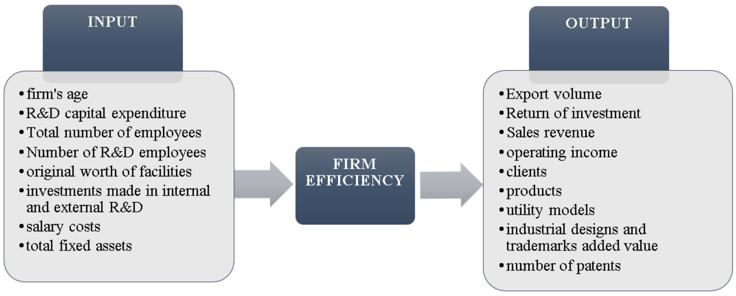

Figure 2: Illustration of efficiency input and output indicators based on literature review (Draft Version).

3 Data, Variables and Research Model

The statistical population examined in this study comprises the TBFs located in Iran's STPs, which have benefited from the support program designed to promote the commercialization of technological innovations, administered by the Vice Presidency for Science and Technology. These firms are generally nascent enterprises operating at medium to high levels of technological maturity, currently in the stages of product commercialization and market entry. To collect relevant input and output data for the analysis, a structured questionnaire was designed based on the indicators outlined in Figure 2. The questionnaire was distributed to all designated STPs involved in the program. Following an assessment of the completeness and reliability of the returned questionnaires, a total of 146 responses from TBFs within 21 STPs were deemed valid and incorporated into the analysis, covering four key input and output indicators. Consequently, the research framework employed in this study is depicted in Figure 3, illustrating the structure and relationships among the variables within the proposed model. A potential concern in panel data analysis is temporal variation. However, several factors ensure the robustness of our findings in this regard: (1) The operational homogeneity of the TBFs, which are predominantly in similar early-growth stages and operate under a unified support program, minimizes the effect of macro-economic variations; (2) Our model specifically uses post-funding metrics, aligning the evaluation window for all firms and isolating the impact of the received support; (3) Statistical analysis via ANOVA revealed no significant efficiency differences across sectors or, by extension, underlying temporal influences (p-value = 0.823).

Figure 3: Research model.

To ensure the validity of the research model, the framework was reviewed by six experts specializing in the field of science and technology. Reliability in the content analysis typically pertains to the level of agreement among evaluators; thus, the reliability coefficients reflect the extent of consensus between experts. In this study, inter-rater reliability was quantified using Cohen's Kappa, as introduced by Stemler in [33]:

$$Kappa = \frac{P_0 - P_e}{1 - P_e},$$

where P_0 denotes the observed agreement and P_e represents the expected agreement by chance. The Kappa value ranges from 0 to 1, with higher values indicating stronger agreement, values above 0.6 are considered acceptable, and those exceeding 0.8 are deemed ideal for expert consensus. The analysis, performed using SPSS software, yielded an average Kappa coefficient of 0.715 across the six experts, indicating a high level of reliability. Additionally, Table 2 presents the cross-tabulation analysis between the researcher and Expert 1, while Table 3 displays the symmetric measures, where the Kappa statistic was 0.84, further confirming substantial agreement.

Table 2: Researcher - Expert 1 cross tabulation.

		Expert 1		
		Input	Output	Total
Researcher	Count	11	0	11
	Expected Count	8.1	1.5	11.0
Input	Count	0	2	3
	Expected Count	2.2	0.4	3.0
Output	Count	0	1	1
	Expected Count	0.7	0.1	1.0
Total	Count	11	2	15
	Expected Count	11.0	2.0	15.0

Table 3: Symmetric measures.

	Asymptotic Significance			
	Kappa Value	Std. Error	Approx. T	Approx. Sig.
Measure of Agreement	0.844	0.135	4.352	0.000
Number of Valid Cases: 15				

Based on the type and topic of the approved projects, the firms included in this study were categorized into nine sectors: electricity and electronics, chemistry and materials, creative industries, information and communication technology, health, agriculture and food industries, construction sector, mechanics and machinery tools, and energy. The technology domains and additional characteristics of the firms under investigation are summarized in Table 4. It is important to note that the companies examined were considered homogeneous according to their inherent nature, as mentioned earlier.

Table 4: Technology field statistics.

Technology Field	Average Size	Number of TBFs	Average Age (Years)
Electrical and Electronics	7	19	8
Chemistry and Materials	7	20	4
Creative Industries	6	9	7
Information & Communication Technology	12	31	7
Healthcare	7	19	5
Agriculture & Food	7	19	9
Construction Industry	14	5	4
Mechanics & Machinery Tools	7	19	5
Energy	6	5	4

As illustrated in Figure 3, the variables utilized in this research are classified into input and output categories, with detailed characteristics summarized in Table 5.

Table 5: Descriptive statistics of input and output variables

Variable	Description	Unit	Min	Max	Mean	Std. Dev.
Input Variables						
Funding (I_1)	Amount of loan received by the firm	10 million IRR	35	220	94	36.5
Number of employees (I_2)	Number of employees after funding	Count	2	57	8	6.8
R&D investment (I_3)	Post-funding R&D expenditure	10 million IRR	2	860	119	150.5
Output Variable						
Income (R_1)	Income generated after funding	10 million IRR	12	1800	309	343.3

3.1 Slacks-Based Measure in DEA (SBM-DEA) Approach

The DEA, particularly through linear programming models, is a nonparametric approach used to evaluate the relative efficiency of DMUs characterized by multiple inputs and outputs. Importantly, DEA does not assume any specific functional form for the production process, nor does it require predetermined weights. It also accommodates variables measured in different units, which enhances its flexibility. The DEA enables the identification of an efficient frontier composed of the most effective DMUs, serving as a benchmark for evaluating the efficiency of less effective units. Consequently, the DEA is widely regarded as an effective benchmarking tool, facilitating the measurement of inefficiencies among non-frontier units and enabling the identification of target performance benchmarks (Cook and Seiford [12]).

As illustrated in Table 1, the literature predominantly employs two DEA models. The first is the CCR model (Charnes et al. [5]), which assumes constant returns to scale (CRS) and forms the foundational frontier model. The second is the BCC model (Banker et al. [2]), which is based on the assumption of variable returns to scale (VRS). Both models can be applied in either an output-oriented or input-oriented fashion, as elaborated by Zhu [39].

The SBM approach, introduced by Tone in 2001 [35], is a notable distance measure within DEA literature. Unlike traditional models such as the CCR and the BCC, which assume proportional changes in inputs and outputs, the SBM is a non-radial model that explicitly accounts for input excesses and output shortfalls, referred to as slacks. This characteristic allows the SBM to directly address the surpluses and deficits of inputs and outputs without relying on proportional scaling. Additionally, the SBM exhibits enhanced stability compared to other DEA models and uniformly considers the surpluses and deficits across all input and output variables. It can accommodate both favorable and unfavorable deviations and can differentiate among units with an efficiency score of one under traditional models [35].

The efficiency score derived from the SBM ranges between 0 and 1, attaining a value of one if and only if the DMU lies on the production frontier with no input or output slacks. Unlike radial efficiency measures that overlook slack variables, the SBM explicitly incorporates them into the efficiency evaluation, thus providing a more comprehensive assessment. The model identifies all sources of inefficiency namely, input excesses and output shortfalls and offers several advantageous properties, including clear efficiency indication, monotonicity, and invariance to units of measurement (Tone et al. [36]).

A key attribute of SBM models is their non-radial nature, which enhances their capacity to accurately determine efficiency, especially when inputs and outputs change both proportionally and disproportionately. However, SBM models do not account for cases where some variables change proportionally while others do not, which can be viewed as a limitation (Cooper et al. [13]). According to the principles of desirability outlined by Fare and Lovell [17], SBM models satisfy three essential criteria: indication of efficiency, invariance to units, and weak monotonicity. Based on these features, the SBM model has been adopted in this study for efficiency assessment. The SBM model (Model 1) abandons the traditional assumption of proportional changes, instead directly incorporating input surpluses and output shortfalls (slacks) into the efficiency assessment. This model is formulated as follows:

$$
\begin{aligned}
\min\ \theta = 1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}} & \\
\text{s.t.}\quad \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{io}, &\qquad i = 1,\ldots,m, \qquad (1)
\end{aligned}
$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro}, \qquad r = 1, \ldots, s,$$
$$s_i^-,\ s_r^+,\ \lambda_j \geq 0, \qquad i = 1, \ldots, m,\ r = 1, \ldots, s,\ j = 1, \ldots, n,$$

where,

1. n denotes the number of evaluated units,
2. m is the number of inputs,
3. s is the number of outputs,
4. x_{ij} and y_{rj} are the inputs and outputs of the j-th unit respectively,
5. s_i^- and s_r^+ are surplus and deficit values of the inputs and outputs of the j-th unit,
6. λ_j is the coverage coefficient of the model for building the frontier, and
7. Ongoing evaluation focuses on the unit (o).

DEA models that incorporate the possibility of adjusting unit indicators can recommend the optimal levels of each indicator necessary to attain full efficiency (100%). However, in cases where some indicators are fixed or must remain constant, such as the number of laborers, the model might suggest practically infeasible adjustments, like reducing the workforce by a fractional number (e.g., 2.5 workers). To address this, Du et al. proposed a modified model that assumes the correctness of certain indicators within collective evaluations [15]. Modified model incorporating fixed and correct indicators referred to as Model (2).

$$
\begin{aligned}
\min\ & z = \theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \\
\text{s.t.}\ & \sum_{j=1}^{n} \lambda_j x_{ij}^{NI} + s_i^- = x_{io}^{NI}, \quad i \in I^{NI}, \\
& \sum_{j=1}^{n} \lambda_j y_{rj}^{NI} - s_r^+ = y_{ro}^{NI}, \quad r \in R^{NI}, \\
& X_i \geq \sum_{j=1}^{n} \lambda_j x_{io}^{I}, \quad i \in I^{I}, \\
& X_i = x_{io}^{I} - s_i^-, \quad i \in I^{I}, \\
& Y_r \geq \sum_{j=1}^{n} \lambda_j y_{ro}^{I}, \quad r \in R^{I}, \\
& Y_r = y_{ro}^{I} - s_r^+, \quad r \in R^{I}, \\
& s_i^-,\ s_r^+,\ \lambda_j \geq 0, \quad X_i, Y_r \in \mathbb{Z}^+, \quad \theta \in \mathbb{R},
\end{aligned}
\tag{2}
$$

where:

1. x_i^I and y_{rj}^I are the correct inputs and outputs, respectively,
2. x_i^{NI} and y_{rj}^{NI} are the incorrect inputs and outputs, respectively,

3. I^{NI} and R^{NI} denote the sets of non-integer and overall outputs/inputs, respectively,

4. I^{I} and R^{I} denote the sets of integer-valued inputs and outputs, respectively.

$$
\begin{aligned}
\min\ \theta = 1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}} & \\
\text{s.t.}\quad \sum_{j=1}^{n}\lambda_j x_{ij}^{NI} + s_i^- = x_{io}^{NI}, & \qquad i \in I^{NI}, \\
\sum_{j=1}^{n}\lambda_j y_{rj} - s_r^+ = y_{ro}, & \qquad r \in R, \\
X_i \geq \sum_{j=1}^{n}\lambda_j x_{io}^{I}, & \qquad i \in I^{I}, \\
X_i = x_{io}^{I} - s_i^-, & \qquad i \in I^{I}, \\
s_i^-,\ s_r^+,\ \lambda_j \geq 0, \quad X_i,\ Y_r \in \mathbb{Z}^+. &
\end{aligned}
$$

3.2 Incorporating Weight Restrictions into the SBM-DEA Model

The accurate measurement of efficiency often requires acknowledging that not all inputs and outputs contribute equally to the production process. Certain factors may be deemed strategically more important or costly than others. To reflect this pragmatic consideration, the standard proposed model can be extended by incorporating pre-defined weights for input shortages and output surpluses. This allows for a more nuanced and managerially relevant efficiency evaluation.

In this section, we present a weighted SBM-DEA model under variable returns to scale (VRS) assumptions. To solve the resulting non-linear fractional program computationally, we employ the Charnes and Cooper [4] transformation to convert it into an equivalent linear model. Consider a set of n Decision Making Units (DMUs). Each DMU j $(j = 1, ..., n)$ uses m inputs x_{ij} $(i = 1, ..., m)$ to produce s outputs y_{rj} $(r = 1, ..., s)$. The efficiency of a specific DMU under evaluation, denoted as DMU_o, is calculated by solving the following weighted SBM model:

Decision variables:

1. λ_j: The weight of DMU_j in constructing the efficient frontier.

2. s_i^-: Slack variable for the i-th input, representing excess input.

3. s_r^+: Slack variable for the r-th output, representing output shortfall.

Weight Parameters:

1. w_i^-: A pre-defined weight for the i-th input slack, reflecting its relative importance (e.g., $w_1^- = 0.5$ for labor, $w_2^- = 0.2$ for capital, $w_3^- = 0.3$ for R&D expenditure).
2. w_r^+: A pre-defined weight for the r-th output slack.

Therefore, the mathematical model (fractional form) is as follows:

$$
\begin{aligned}
\min \quad & \rho = \frac{1 - \sum_{i=1}^{m} w_i^- \dfrac{s_i^-}{x_{io}}}{1 + \sum_{r=1}^{s} w_r^+ \dfrac{s_r^+}{y_{ro}}}, \\
\text{s.t.} \quad & \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io}, \quad i = 1, \ldots, m, \\
& \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro}, \quad r = 1, \ldots, s, \\
& \sum_{j=1}^{n} \lambda_j = 1 \quad \text{(VRS condition)}, \\
& \lambda_j \geq 0, \quad s_i^- \geq 0, \quad s_r^+ \geq 0.
\end{aligned} \tag{3}
$$

In this model:

1. The numerator $\left(1 - \sum_{i=1}^{m} w_i^- \frac{s_i^-}{x_{io}}\right)$ represents the weighted mean proportional reduction of inputs.
2. The denominator $\left(1 + \sum_{r=1}^{s} w_r^+ \frac{s_r^+}{y_{ro}}\right)$ represents the weighted mean proportional expansion of outputs.
3. The constraint $\sum \lambda_j = 1$ imposes the Variable Returns to Scale (VRS) assumption.

The model presented in (3) is a non-linear fractional program. To solve it efficiently, we apply the Charnes and Cooper [4] transformation, which converts it into an equivalent linear programming problem. We define a scalar variable $T > 0$ and introduce the following variable substitutions:

$$\mu_j = T\lambda_j, \qquad \beta_i = T\frac{s_i^-}{x_{io}}, \qquad \gamma_r = T\frac{s_r^+}{y_{ro}}.$$

Applying this transformation yields the following linear model:

$$
\begin{aligned}
\min \quad & T - \sum_{i=1}^{m} w_i^- \beta_i \\
\text{s.t.} \quad & T + \sum_{r=1}^{s} w_r^+ \gamma_r = 1, \\
& \sum_{j=1}^{n} \mu_j x_{ij} + \beta_i x_{io} = T x_{io}, \quad i = 1, \ldots, m,
\end{aligned}
$$

$$\sum_{j=1}^{n} \mu_j y_{rj} - \gamma_r y_{ro} = T y_{ro}, \quad r = 1, \ldots, s,$$
$$\sum_{j=1}^{n} \mu_j = T,$$
$$\mu_j \geq 0, \quad \beta_i \geq 0, \quad \gamma_r \geq 0, \quad T \geq \epsilon.$$

This linear model can be effectively solved using standard linear programming solvers. Upon solving, the efficiency score ρ^* for DMU_o is obtained from the objective function value: $\rho^* = T^* - \sum_i w_i^- \beta_i^*$. This approach provides a computationally efficient method for integrating decision-makers' preferences regarding the relative importance of different performance indicators into the DEA framework.

4 Research Findings

In this study, the efficiency of TBFs located in STPs was assessed using two complementary models. Initially, the standard SBM model was applied, with its comprehensive results including detailed information on the three inputs, one output, efficiency scores, and the ranking of each DMU—presented in Table 9 (Parts 1-8; see Section 7).To incorporate decision-makers' strategic preferences, the analysis was extended using a weighted SBM model, which assigned expert-derived weights to strategic inputs based on a survey of six industry experts: R&D investment ($w_{I_3} = 0.5$), number of employees ($w_{I_2} = 0.3$), and funding ($w_{I_1} = 0.2$). The data analysis for both models was performed using GAMS software. The complete results of the weighted model, which induced a significant reshuffling in DMU rankings, are presented in Table 11 (Parts 1-8). Each DMU's performance is expressed through an efficiency score ranging from 0 to 1, where a score of 1 indicates full efficiency. The results of the weighted model reveal that, out of a total of 146 units analyzed, five units (3.4%) achieved full efficiency, namely DMU002, DMU043, DMU083, DMU113 and DMU131. While the number of fully efficient units has changed little compared to the unweighted model, the re-ranking reflects a new priority structure. Furthermore, Tables 10 and 12 introduces the benchmark units for inefficient units to achieve optimal efficiency levels under the weighted SBM model, identifying DMU002, DMU043, DMU083, DMU113 and DMU131 as the key reference units. The findings from the prioritized model indicate that the majority of the units are weak in converting their inputs into outputs, particularly in generating income and effectively utilizing strategic inputs like R&D investments. The weighted model provides a more realistic and managerially relevant assessment aligned with the strategic goals of technology-based firms.

4.1 Comparing Efficiency Among Firms of Each Sector

Another issue that has been investigated in this research is the comparison of the efficiency of TBFs in each sector. The results of the survey in Table 6 show that the companies in the fields of electricity and electronics, agriculture and food industries, and creative industries have had the highest efficiency scores, respectively.

Table 6: Efficiency of TBFs by sector.

Sector	SBM Efficiency	Rank
Electrical and Electronics	0.28	1
Agriculture and Food Industry	0.28	1
Creative Industries	0.27	2
Information and Communications Technology	0.23	3
Health	0.22	4
Chemistry and Materials Energy	0.21	5
Mechanics and Machine Tools	0.18	6
Building Industry	0.15	7

A notable observation from Table 6 is the consistently low efficiency scores across all sectors. Given that only 2.7% of DMUs were identified as efficient, the potential influence of outliers on the efficiency frontier was rigorously examined. To ensure the robustness of our results, we conducted a sensitivity analysis using the leave-one-out cross-validation method, following the approach of Johnson and McGinnis [23]. Furthermore, a Super-SBM model was applied to detect and assess the impact of super-efficient units. The results confirmed that no single DMU disproportionately influenced the construction of the efficiency frontier, and the overall distribution of efficiency scores remained stable. Therefore, the low efficiency is not an artifact of outliers but reflects a systemic characteristic of the firms under study. As evidenced by the data in Table 6, the average efficiency across different sectors is relatively similar, with scores clustering around the 0.15–0.28 range. To statistically examine whether significant differences exist among sector means, an Analysis of Variance (ANOVA) test was conducted using SPSS software. The hypotheses tested were:

$$H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7 = \mu_8 = \mu_9,$$
$$H_1 : \text{At least the average efficiency of two sectors is not the same.}$$

The related results are reported in Table 7.

Table 7: ANOVA results.

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.206	8	0.026	0.542	0.823
Within Groups	6.498	137	0.047		
Total	6.704	145			

The significance value (p-value) exceeds 0.05, indicating that the null hypothesis H_0 cannot be rejected. Consequently, there is no statistically significant difference in the average efficiency scores across sectors. In other words, the efficiency levels are similar regardless of sector classification. This finding contrasts with prior research (e.g., Erena et al. [16]; Heng Chen et al. [8]). The near-uniformity of sector efficiencies, as reflected in Table 6, can be attributed to the homogeneity of the sample in fundamental characteristics such as age and size. The variance analysis further corroborates this conclusion.

4.2 In-Depth Investigation of the Efficient TBFs

Given the objective of this study to provide actionable insights for other firms through benchmarking of successful examples, a detailed analysis was conducted on four highly efficient TBFs via interviews with their CEOs. The goal was to identify the core features and key characteristics that have contributed to their success. The salient points from these interviews are summarized in Table 8.

5 Discussion

TBFs are among the most vital actors in the national innovation system (Maine et al. [28]). However, their potential is often hampered by challenges such as limited capabilities, high risks, and difficulties in market entry, prompting governmental intervention to support these firms. Since 2014, Iran has implemented a comprehensive scheme aimed at promoting the commercialization of technological products across all Iranian STPs. Effective allocation of scarce resources remains a critical concern for sustaining these firms and boosting the economy. This study assessed the efficiency of 146 TBFs within STPs during 2021–2023, utilizing the SBM-DEA model. Benchmark units were proposed for each firm to guide their performance improvement strategies. Several noteworthy findings emerge from the comparison with previous research. Furthermore, the incorporation of a weight restriction led to a more realistic distribution of efficiency scores and reinforcing our conclusion that inefficient firms struggle significantly with commercialization and revenue generation, not just with input utilization.

Firstly, the study reveals that the average efficiency level of Iranian TBFs is only 2.7%, a stark contrast to earlier estimates, such as those by Chen et al. [9] and Erena et al. [16] which reported substantially higher efficiency levels within firms located in STPs. For example, Chen et al. [9] found that most Taiwanese computer and peripheral firms were technically efficient, a disparity likely attributable to several factors:

1. **Firm Maturity and Market Environment:** Iranian TBFs are relatively young and possess limited commercialization experience, while Taiwanese firms benefit from more mature markets.
2. **Output Measures:** Prior studies often employed broader output indicators such as patent counts or export volumes, which may better reflect firm performance.
3. **Sectoral Variations:** Unlike studies by Heng Chen et al. [8] and Grilo and Santos [20], which reported substantial efficiency differences across sectors, this study found no statistically significant sectoral disparity. This suggests systemic inefficiencies, related to poor commercialization infrastructure and constrained market access, are the primary issues rather than sector-specific factors.
4. **Management and Benchmarking:** Similar to Grilo and Santos [20], this research sets some constraints for efficient firms to serve as benchmarks. Additionally, it offers qualitative insights

Table 8: Key features and characteristics of the efficient TBFs.

Code	Province	Product Title	Age	Key Features and Characteristics
2	Qom	Methodical presentation of religious concepts	7	- Selling products through IT, - Effective marketing strategies, - Acquiring licenses and approvals, - Designing products based on market needs, - Exporting products internationally.
43	Hormozgan	Electronic system for selling marine products	6	- Attracting private sector investment, - Aligning with location capabilities, - Innovative IT methods in ordering, - Securing facilities from financial institutions, - Obtaining production licenses.
83	Zanjan	Laboratory kit for genotyping	5	- Recruiting specialized human resources, - Direct investment in projects.
113	Fars	Control valves	6	- Obtaining permits and sales approval, - Acquiring a business registration, - Registering trademarks, - Recruiting qualified personnel, - Attracting financial facilities from other institutions.
131	Hamedan	Agriculture and Food industry	8	- Private sector investment, - Attracting specialized human resources, - Obtaining licenses and standards, - Diversifying the product portfolio, - Having an export plan to neighboring countries.

into the reasons behind success, such as strategic marketing and private capital mobilization, providing valuable guidance for managers and policymakers.

The findings indicate that the systemic inefficiencies observed among Iranian TBF are consistent with those identified in previous studies, such as Khayatian et al. [24]. The systemic challenges inhibiting Iranian TBFs include:

1. **Lack of Commercialization Support:** Consistent with Geisler and Torchetti (2015), the study emphasizes the need for enhanced support mechanisms to help firms translate technological in-

novations into marketable products. Despite government programs providing low-interest loans, many firms struggle to bridge the gap between innovation and commercialization.

2. **Limited Marketing Skills:** Aligning with Yaghoubi et al. [38], findings indicate that technological excellence alone does not guarantee success. Effective marketing is crucial; therefore, targeted interventions are necessary to strengthen market presence.

3. **Resource Utilization Inefficiency:** The inefficient use of inputs like R&D investments corroborates the findings of Chen and Breedlove [7] that mismanagement of subsidies hampers innovation performance.

This paper enriches the broader discussion on supporting TBFs in emerging economies by offering several valuable insights:

- **Reform Policy:** Unlike developed countries where TBFs leverage sophisticated venture capital markets (e.g., Grilo and Santos [20]), Iranian TBFs predominantly depend on government funding. Consequently, policymakers should prioritize creating an enabling environment that fosters private sector engagement, such as through tax incentives for venture capital investments or the development of public-private partnerships.

- **Customized Support Programs:** While financial instruments like low-interest loans are vital, sustained support structures, such as capacity-building initiatives in marketing, certification processes, and regulatory compliance, are essential for long-term success. These recommendations echo Fukugawa findings [19], which emphasize the importance of tailored support programs for startups operating within science parks.

- **Demand-Side Policy Integration:** The study advocates for strategies aimed at stimulating market demand via public procurement and fostering collaborations between TBFs and established industries. This aligns with Maine et al. [28], who highlighted the critical role of demand-side policies in nurturing innovation ecosystems and facilitating sustainable growth of technological firms.

6 Conclusions and Suggestions

Performance evaluation is a critical concern for managers, serving as a fundamental reference for decision-making regarding budget allocation and strategic improvements. The DEA, particularly the SBM model, is a robust management tool for assessing the efficiency of homogeneous units, identifying both efficient and inefficient entities, and pinpointing sources of inefficiency. Since its inception in 1978, the DEA has been extensively applied across diverse sectors, notably for determining efficiency levels, diagnosing inefficiencies, and formulating improvement strategies.

In this study, both standard and weighted SBM models were utilized to evaluate the efficiency of 146 Iranian TBFs. The weighted model incorporated expert-derived strategic weights obtained through a comprehensive survey of six industry experts: Funding (0.2), Number of Employees (0.3), and R&D Investment (0.5). While the weighted approach identified five efficient firms (3.4%) compared to four (2.7%) in the standard model, the relatively modest change in the number of efficient units indicates that strategic weighting primarily induced rank reshuffling rather than fundamentally altering the overall efficiency landscape. This suggests that systemic inefficiencies persist across most firms, regardless of the evaluation criteria employed.

The majority of firms exhibited significant weaknesses in converting inputs into outputs, highlighting systemic issues such as resource underutilization and operational inefficiencies. These results suggest that the current support mechanisms are insufficient to achieve optimal performance, underlining the necessity for targeted policy interventions.

In-depth investigation of the efficient TBFs, particularly the newly identified efficient unit DMU131 in the weighted model, revealed distinctive characteristics. This firm demonstrated exceptional performance in strategically weighted indicators, particularly R&D investment efficiency, serving as a valuable benchmark for other firms seeking to optimize their resource allocation according to expert-prioritized criteria.

Based on comprehensive analysis and in-depth examination of high-performing firms, the following key insights and recommendations are proposed:

- **Supporting Technology Commercialization:** Given the reliance of TBFs on R&D, coupled with high costs and time burdens associated with commercialization, particularly for small and early-stage firms, there is a pressing need for policies that facilitate access to alternative sources of funding, including venture capital, risk investment funds, and enhanced support within science and technology parks.

- **Facilitating Approvals and Standards Acquisition:** Streamlining procedures for obtaining necessary licenses, standards, and permits can significantly boost output and efficiency. Support policies aimed at reducing bureaucratic barriers should be prioritized to accelerate market entry and scale-up processes.

- **Enhancing Marketing Capabilities:** While technological innovation is vital, effective marketing efforts are essential to translate technological advancements into sales and market share. Efforts to strengthen marketing skills, through training programs, advisory services, and government-led initiatives, are crucial. To maximize technology's competitive advantage, a combination of government support and demand-stimulation tools (such as public procurement and industry partnerships) should be employed.

- **Addressing Systemic and Structural Inefficiencies:** The low number of efficient firms indicates systemic issues within the innovation support ecosystem. Although extensive government assistance exists, the conversion of technological innovations into market-ready products remains limited, revealing misalignments in the commercialization pipeline and support structures.

- **Balanced Benchmarking and Knowledge Transfer:** The expanded set of reference units (including DMU002, DMU043, DMU083, DMU113, and DMU131) provides diverse benchmarking opportunities. Establishing mechanisms for peer learning, mentorship, and cross-firm knowledge transfer, facilitated by science parks and policy organizations, could foster broader capacity-building.

- **Input-Output Alignment and Resource Utilization:** Analysis indicates many firms invest heavily in R&D, personnel, and public support tools without corresponding growth in commercialization outputs such as sales or exports. Addressing these mismatches requires refining resource allocation strategies and support mechanisms to enhance effectiveness.

- **Cross-Sector Learning:** Inefficiency was not confined to specific sectors, implying systemic issues across industries. Promoting cross-sector practices and knowledge sharing can lead to systemic improvements in efficiency and innovation performance.

- **Policy Design and Intervention Strategies:** Policymakers should revisit support schemes, incorporating post-investment monitoring, milestone-based support, and non-monetary assistance such as market access training and operational guidance. Tiered support tailored to firm size, technology maturity, and sectoral needs can optimize resource allocation and impact.

6.1 Limitations and Future Directions

This research initially employed an unconstrained SBM model. providing flexible weight allocation but lacking consideration of indicator importance, a factor that could be addressed by incorporating weight restrictions in future models. To address the inherent limitation of traditional DEA in assigning equal priority to all indicators, we developed and applied an expert-driven weighted SBM model, which incorporated preferential weights for strategic inputs derived from a survey of six industry experts: Funding (0.2), Number of Employees (0.3), R&D Investment (0.5). This enhancement significantly improved the practical relevance of our efficiency assessment. Additionally, the reference units for inefficient firms were derived from a single optimal solution; exploring multiple or global benchmarks (e.g., via Maximal Reference Set (MRS) or Global Reference Set (GRS) approaches) could enhance the robustness of the analysis. Data limitations restricted the evaluation of additional performance indicators such as patents, export volumes, or market share, which could provide deeper insights into firm performance. Future studies should incorporate these metrics to enrich analysis.

Examining efficiency across different firm types and sectors yielded no significant differences, suggesting systemic inefficiencies. Future research could employ categorical or cluster-specific DEA models to capture intra-sectoral variations and explore geographic influences on efficiency, with larger sample sizes. Complementary qualitative methods such as interviews, case studies, and operational audits can provide nuanced understanding of operational challenges. Combining the DEA with regression analysis may also help identify key predictors of efficiency or inefficiency. Finally, while this study focused on Iranian TBFs, its insights may be relevant to other developing countries sharing similar innovation ecosystems. Extending this research to comparative analyses could facilitate broader knowledge transfer and policy learning.

7 Appendix

In this section, we provide the complete numerical results of the Slack-Based Measure (SBM) Data Envelopment Analysis (DEA) model applied to the 146 technology-based firms (TBFs) under study. The analysis was conducted using GAMS software, employing both the standard SBM model and the weighted SBM model that incorporates preferential weights derived from an expert survey. Through a comprehensive survey of six industry experts, the following strategic weights were determined: Funding (0.2), Number of Employees (0.3), and R&D Investment (0.5). The tables are organized as follows:

1. **Table 9** presents the detailed results of the standard SBM model, including three inputs (Funding, Number of Employees, R&D Investment), one output (Income), efficiency scores, rankings, and corresponding slack values for each DMU.

2. **Table 11** presents the comprehensive results of the weighted SBM model, demonstrating how the incorporation of expert-derived strategic weights significantly reshuffles the efficiency rankings and provides a more managerially relevant assessment aligned with industry priorities.

3. **Tables 10 and 12** introduce the benchmark units for inefficient DMUs to achieve optimal efficiency levels under the weighted SBM model, identifying DMU002, DMU043, DMU083, DMU113, and DMU131 as the key reference units that exhibit best practices according to the expert-prioritized strategic criteria.

The comparative analysis of both models reveals important insights into the efficiency structures of TBFs, highlighting how strategic prioritization of inputs affects performance evaluation and identifying distinct patterns of inefficiency that would remain obscured in traditional DEA applications.

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 1)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
1	Electrical and electronics	DMU001	1666666.7	1	933333.33	30000000	48333333.33	11	89066666.67	0.0423	138
2	Creative industries	DMU002	70000000	12	10000000	800000000	–	–	–	1	1
3	Chemistry and materials	DMU003	26250000	5	3750000	300000000	73750000	2	6250000	0.4506	15
4	Chemistry and materials	DMU004	11111111	1	6222222.2	200000000	118888888.9	3	3777777.78	0.3192	24
5	ICT	DMU005	7152777.8	1	2180555.6	100000000	52847222.22	6	27819444.44	0.1116	93
6	Electrical and electronics	DMU006	9527777.8	1	4605555.6	160000000	70472222.22	3	25394444.44	0.1742	57
7	Chemistry and materials	DMU007	11111111	1	6222222.2	200000000	78888888.89	14	93777777.78	0.0841	114
8	Health	DMU008	8333333.3	1	4666666.7	150000000	46666666.67	3	55333333.33	0.1598	66
9	Mechanics and machine tools	DMU009	6666666.7	1	3733333.3	120000000	73333333.33	1	76266666.67	0.2100	50
10	Electrical and electronics	DMU010	3500000	1	500000	40000000	56500000	4	19500000	0.0944	104
11	Electrical and electronics	DMU011	43333333	4	24266667	780000000	36666666.67	7	475733333.3	0.3179	25
12	Health	DMU012	10000000	1	5600000	180000000	80000000	4	87400000	0.1238	86
13	Mechanics and machine tools	DMU013	5965277.8	1	968055.56	70000000	94034722.22	2	34031944.44	0.1402	80
14	ICT	DMU014	2625000	1	375000	30000000	47375000	12	9625000	0.0556	134
15	Chemistry and materials	DMU015	18888889	2	10577778	340000000	36111111.11	4	89422222.22	0.2608	36
16	Electrical and electronics	DMU016	29375000	3	14625000	500000000	70625000	15	15375000	0.3160	26
17	Electrical and electronics	DMU017	1388888.9	1	777777.78	25000000	88611111.11	4	59222222.22	0.0761	122
18	Electrical and electronics	DMU018	6361111.1	1	1372222.2	80000000	83638888.89	6	38627777.78	0.0826	115

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 2)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
19	Agriculture and Food industry	DMU019	55555556	5	31111111	1000000000	44444444.44	1	48888888.89	0.5926	10
20	Chemistry and materials	DMU020	2222222.2	1	1244444.4	40000000	97777777.78	5	11475555.6	0.0665	130
21	Information and Commu-nications Technol-ogy	DMU021	25833333	3	14466667	465000000	74166666.67	7	13553333.3	0.2183	48
22	Building industry	DMU022	30000000	3	16800000	540000000	70000000	24	18320000.0	0.165	61
23	Agriculture and Food industry	DMU023	51597222	5	27069444	900000000	8402777.778	2	2930555.556	0.8255	3
24	Mechanics and machine tools	DMU024	2222222.2	2	12444444	400000000	47777777.78	5	28755555.6	0.2149	49
25	Chemistry and materials	DMU025	12777778	2	7155555.6	230000000	37222222.22	5	42844444.44	0.2281	44
26	Health	DMU026	7777777.8	1	4355555.6	140000000	37222222.22	3	65644444.44	0.1617	64
27	Information and Commu-nications Technol-ogy	DMU027	11111111	1	6222222.2	200000000	48888888.89	5	83777777.78	0.1403	79
28	Information and Commu-nications Technol-ogy	DMU028	2222222.2	2	12444444	400000000	27777777.78	2	27555555.56	0.4185	18
29	Agriculture and Food industry	DMU029	27777778	3	15555556	500000000	22222222.22	13	74444444.44	0.3033	28
30	Chemistry and materials	DMU030	25733333	3	10906667	408000000	74266666.67	8	19093333.33	0.2979	29
31	Chemistry and materials	DMU031	1666666.7	1	933333.33	30000000	78333333.33	5	79066666.67	0.0664	131
32	Mechanics and machine tools	DMU032	3500000	1	500000	40000000	76500000	3	29500000	0.1035	96
33	Information and Commu-nications Technol-ogy	DMU033	1666666.7	1	933333.33	30000000	38333333.33	29	79066666.67	0.0289	140
34	Information and Commu-nications Technol-ogy	DMU034	50000000	5	28000000	900000000	40000000	20	47200000	0.2705	31

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 3)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
35	Creative industries	DMU035	1050000	1	150000	12000000	38950000	5	1350000	0.0976	101
36	Creative industries	DMU036	7152777.8	1	2180555.6	100000000	52847222.22	3	7819444.444	0.1958	52
37	Creative industries	DMU037	10555556	1	74777778	250000000	49444444.44	4	77522222.2	0.1546	70
38	Agriculture and Food industry	DMU038	11111111	1	6222222.2	200000000	78888888.89	14	93777777.78	0.0841	114
39	Mechanics and machine tools	DMU039	19444444	2	10888889	350000000	80555555.56	7	15111111.1	0.1613	65
40	Agriculture and Food industry	DMU040	7222222.2	1	4044444.4	130000000	72777777.78	6	64595555.6	0.0798	118
41	Information and Commu-nications Technol-ogy	DMU041	20000000	2	11200000	360000000	20000000	7	48880000	0.2482	41
42	Agriculture and Food industry	DMU042	10000000	1	5600000	180000000	70000000	3	14440000	0.1374	81
43	Information and Commu-nications Technol-ogy	DMU043	60000000	6	860000000	180000000	–	–	–	1	1
44	Chemistry and materials	DMU044	2625000	1	375000	30000000	57375000	4	5625000	0.1021	97
45	Agriculture and Food industry	DMU045	44444444	4	24888889	800000000	55555555.56	3	40911111.1	0.3577	21
46	Building industry	DMU046	8333333.3	1	4666666.7	150000000	91666666.67	12	71333333.33	0.0739	124
47	Agriculture and Food industry	DMU047	17888889	1	14977778	240000000	72111111.11	3	10502222.2	0.1912	53
48	Electrical and elec-tronics	DMU048	50000000	5	28000000	900000000	30000000	3	42200000	0.4374	17
49	Mechanics and machine tools	DMU049	2625000	1	375000	30000000	97375000	7	49625000	0.0529	137
50	Health	DMU050	16666667	2	9333333.3	300000000	43333333.33	4	14066666.7	0.2244	47
51	Chemistry and materials	DMU051	7777777.8	1	4355555.6	140000000	92222222.22	2	29564444.4	0.1419	77
52	Mechanics and machine tools	DMU052	11111111.1	1	622222.2	20000000	78888888.89	3	19937777.8	0.089	109
53	Energy	DMU053	8333333.3	1	4666666.7	150000000	81666666.67	2	65333333.33	0.1642	62

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 4)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
54	Energy	DMU054	7152777.8	1	2180555.6	100000000	42847222.22	3	17819444.44	0.1674	59
55	Information and Communications Technology	DMU055	–	–	–	–	–	–	–	0.1533	72
56	Agriculture and Food industry	DMU056	16666667	2	9333333.3	300000000	53333333.33	55	40666666.67	–	–
57	Energy	DMU057	7152777.8	1	2180555.6	100000000	142847222.2	4	47819444.44	0.0971	102
58	Agriculture and Food industry	DMU058	41666667	4	23333333	750000000	98333333.33	6	195666666.7	0.2681	33
59	Agriculture and Food industry	DMU059	7152777.8	1	2180555.6	100000000	122847222.2	2	27819444.44	0.1537	71
60	Electrical and electronics	DMU060	11111111	1	6222222.2	200000000	168888888.9	7	73777777.78	0.0882	111
61	Mechanics and machine tools	DMU061	7944444.4	1	2988888.9	120000000	92055555.56	10	27011111.11	0.09	107
62	Information and Communications Technology	DMU062	8333333.3	1	4666666.7	150000000	121666666.7	4	95333333.33	0.1036	95
63	Information and Communications Technology	DMU063	4375000	1	625000	50000000	145625000	5	29375000	0.0722	127
64	Chemistry and materials	DMU064	4375000	1	625000	50000000	90625000	8	9375000	0.0732	125
65	Agriculture and Food industry	DMU065	7152777.8	1	2180555.6	100000000	112847222.2	2	27819444.44	0.1552	69
66	Information and Communications Technology	DMU066	8333333.3	1	4666666.7	150000000	91666666.67	2	185333333.3	0.1471	74
67	Building industry	DMU067	6361111.1	1	1372222.2	80000000	93638888.89	4	38627777.78	0.0993	100
68	Information and Communications Technology	DMU068	9131944.4	1	4201388.9	150000000	120868055.6	11	35798611.11	0.0862	113
69	Information and Communications Technology	DMU069	7944444.4	1	2988888.9	120000000	92055555.56	6	47011111.11	0.094	105
70	Creative industries	DMU070	39375000	7	5625000	450000000	50625000	–	4375000	0.6667	6

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 5)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
71	Health	DMU071	15833333	2	8866666.7	285000000	119166666.7	6	116133333.3	0.1461	76
72	Health	DMU072	15000000	2	8400000	270000000	60000000	4	41600000	0.2338	43
73	Electrical and electronics	DMU073	16284722	2	6381944.4	250000000	78715277.78	5	13618055.56	0.2587	37
74	Health	DMU074	6756944.4	1	1776388.9	90000000	73243055.56	10	34223611.11	0.0749	123
75	Information and Communications Technology	DMU075	16284722	2	6381944.4	250000000	53715277.78	5	33618055.56	0.226	46
76	Information and Communications Technology	DMU076	5000000	1	2800000	90000000	80000000	9	57200000	0.0685	129
77	Electrical and electronics	DMU077	8055555.6	1	4511111.1	145000000	76944444.44	2	60488888.89	0.1658	60
78	Mechanics and machine tools	DMU078	3150000	1	4500000	36000000	66850000	9	17550000	0.0567	133
79	Health	DMU079	5555555.6	1	3111111.1	100000000	34444444.44	1	26888888.89	0.2475	42
80	Health	DMU080	16666667	2	9333333.3	300000000	63333333.33	5	40666666.67	0.2269	45
81	Chemistry and materials	DMU081	1111111	1	6222222.2	200000000	78888888.89	2	93777777.78	0.173	58
82	Electrical and electronics	DMU082	5555555.6	5	3111111	100000000	14444444.44	1	16888888.89	0.5942	9
83	Health	DMU083	90000000	2	100000000	80000000	–	–	–	1	1
84	Information and Communications Technology	DMU084	5555555.6	1	3111111.1	100000000	44444444.44	7	46888888.89	0.0994	99
85	Information and Communications Technology	DMU085	27777778	3	1555555.6	500000000	62222222.22	17	18444444.44	0.1788	55
86	Mechanics and machine tools	DMU086	3150000	1	4500000	36000000	116850000	2	9550000	0.1349	83
87	Mechanics and machine tools	DMU087	51597222	5	27069444	90000000	28402777.78	1	2930555.556	0.7935	4
88	Creative industries	DMU088	2625000	1	3750000	30000000	87375000	8	19625000	0.053	136
89	Agriculture and Food industry	DMU089	3611111	4	2022222	65000000	63888888.89	8	12977777.78	0.2764	30

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 6)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
90	Agriculture and Food industry	DMU090	55555556	5	31111111	1000000000	14444444.44	16888888.9	–	0.6497	7
91	Chemistry and materials	DMU091	66472222	4	53344444	930000000	53527777.78	44665555.6	–	0.5535	12
92	Information and Commu-nications Technol-ogy	DMU092	39166667	2	34333333	500000000	30833333.33	22566666.7	–	0.5639	11
93	Information and Commu-nications Technol-ogy	DMU093	7152777.8	1	2180555.6	100000000	77847222.22	17819444.44	–	0.1199	89
94	Information and Commu-nications Technol-ogy	DMU094	27777778	3	15555556	500000000	22222222.22	54444444.44	–	0.3704	19
95	Mechanics and machine tools	DMU095	15493056	2	5573611.1	230000000	64506944.44	14426388.89	–	0.2686	32
96	Chemistry and materials	DMU096	8333333.3	1	4666666.7	150000000	91666666.67	29533333.3	–	0.1163	91
97	Energy	DMU097	13888889	2	7777777.8	250000000	76111111.11	10222222.2	–	0.1417	78
98	Electrical and elec-tronics	DMU098	10111111	3	10622222	1000000000	18888888.89	19377777.8	–	0.7322	5
99	Electrical and elec-tronics	DMU099	16666667	2	9333333.3	300000000	11333333.3	14066666.7	–	0.1746	56
100	Creative industries	DMU100	4375000	1	625000	500000000	95625000	49375000	–	0.1299	85
101	Information and Commu-nications Technol-ogy	DMU101	13888889	2	7777777.8	250000000	11611111.11	92222222.22	–	0.1356	82
102	Chemistry and materials	DMU102	7152777.8	1	2180555.6	100000000	19284722.2	47819444.44	–	0.082	116
103	Information and Commu-nications Technol-ogy	DMU103	19444444	2	10888889	350000000	80555555.56	13911111.1	–	0.2001	51
104	Building industry	DMU104	55555556	5	31111111	1000000000	12444444.4	21888888.9	–	0.2634	34
105	Energy	DMU105	11111111	1	6222222.2	200000000	88888888.89	73777777.78	–	0.1463	75
106	Mechanics and machine tools	DMU106	3888888.9	1	2177777.8	700000000	46111111.11	47822222.22	–	0.0881	112

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 7)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
107	Information and Communications Technology	DMU107	1444444.4	1	808888.89	26000000	68555555.56	23	79191111.11	0.0241	141
108	Mechanics and machine tools	DMU108	7152777.8	1	2180555.6	100000000	112847222.2	9	17819444.44	0.0895	108
109	Creative industries	DMU109	22312500	4	3187500	255000000	77687500	2	1812500	0.5091	14
110	Agriculture and Food industry	DMU110	2666666.7	1	1493333.3	48000000	87333333.33	4	98506666.67	0.0815	117
111	Electrical and electronics	DMU111	29000000	3	16240000	522000000	41000000	1	83760000	0.4422	16
112	Chemistry and materials	DMU112	5555555.6	1	3111111.1	100000000	74444444.44	5	46888888.89	0.0994	99
113	Electrical and electronics	DMU113	100000000	9	56000000	180000000	–	–	–	1	1
114	Health	DMU114	2500000	1	1400000	45000000	92500000	4	29860000	0.077	121
115	Mechanics and machine tools	DMU115	5250000	1	750000	60000000	10475000	2	7250000	0.1583	68
116	Information and Communications Technology	DMU116	2222222.2	1	1244444.4	40000000	37777777.78	6	33755555.56	0.078	120
117	Information and Communications Technology	DMU117	29375000	3	14625000	500000000	50625000	24	15375000	0.3219	22
118	Health	DMU118	33333333	3	18666667	600000000	56666666.67	6	38133333.33	0.2501	38
119	Health	DMU119	11111111	1	6222222.2	200000000	83888888.89	5	68777777.78	0.1222	88
120	Agriculture and Food industry	DMU120	2625000	1	375000	30000000	72375000	5	9625000	0.0797	119
121	Information and Communications Technology	DMU121	16666667	2	9333333.3	300000000	48333333.33	10	14066666.7	0.1618	63
122	Building industry	DMU122	11111111	1	6222222.2	200000000	48888888.89	3	14377777.8	0.1589	67
123	Chemistry and materials	DMU123	2625000	1	375000	30000000	67375000	6	1625000	0.1226	87
124	Information and Communications Technology	DMU124	11111111	1	6222222.2	200000000	23888888.89	2	13777777.78	0.3206	23

Table 9: Appendix. Results of the DEA model for Iranian TBFs (Part 8)

NO	Sector	Code	Improvement				Slacks			SBM Efficiency	Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
125	Information and Communications Technology	DMU125	1388888.9	1	777777.78	25000000	38611111.11	9	29222222.22	0.0535	135
126	Mechanics and machine tools	DMU126	18263889	2	8402777.8	300000000	131736111.1	3	11597222.22	0.314	27
127	Mechanics and machine tools	DMU127	7152777.8	1	2180555.6	100000000	42847222.22	5	2819444.44	0.2486	40
128	Health	DMU128	55555556	5	31111111	1000000000	69444444.44	4	368888888.9	0.3593	20
129	Agriculture and Food industry	DMU129	5250000	1	750000	60000000	114750000	14	9250000	0.0618	132
130	Agriculture and Food industry	DMU130	7152777.8	1	2180555.6	100000000	117847222.2	4	21819444.44	0.116	92
131	Agriculture and Food industry	DMU131	84930556	8	45736111	1500000000	15069444.44		4263888.89	0.9213	2
132	Information and Communications Technology	DMU132	29375000	3	14625000	500000000	110625000		20375000	0.5426	13
133	Creative industries	DMU133	8333333.3	1	4666666.7	150000000	141666666.7	1	295333333.3	0.1904	54
134	Chemistry and materials	DMU134	50000000	5	28000000	900000000	50000000	26	292000000	0.2496	39
135	Chemistry and materials	DMU135	78333333	4	68666667	1000000000	71666666.67		131333333.3	0.6219	8
136	Mechanics and machine tools	DMU136	7548611.1	1	2584722.2	110000000	122451388.9	10	37415277.78	0.0712	128
137	Health	DMU137	16666667	2	9333333.3	300000000	53333333.33	18	70666666.67	0.1516	73
138	Health	DMU138	7152777.8	1	2180555.6	100000000	162847222.2	3	17819444.44	0.1337	84
139	Chemistry and materials	DMU139	4375000	1	625000	50000000	175625000	3	99375000	0.0935	106
140	Health	DMU140	28055556	1	28111111	300000000	131944444.4	2	71888888.89	0.2633	35
141	Electrical and electronics	DMU141	7944444.4	1	2988888.9	120000000	152055555.6	5	57011111.11	0.0887	110
142	Mechanics and machine tools	DMU142	5555555.6	1	3111111.1	100000000	154444444.4	16	196888888.9	0.0364	139
143	Electrical and electronics	DMU143	9131944.4	1	4201388.9	150000000	210868055.6	6	115798611.1	0.0731	126
144	Health	DMU144	22222222	2	12444444	400000000	177777777.8	9	187555555.6	0.1184	90
145	Health	DMU145	7152777.8	1	2180555.6	100000000	132847222.2	4	27819444.44	0.1079	94
146	Electrical and electronics	DMU146	11111111	1	6222222.2	200000000	138888888.9	5	93777777.78	0.101	98

Table 10: Appendix. Introducing benchmark units for inefficient units achieve optimal efficiency levels

References				
DMU002	DMU043	DMU083	DMU113	
DMU001			Y	
DMU002	Y			
DMU003	Y			
DMU004			Y	
DMU005	Y		Y	
DMU006	Y		Y	
DMU007			Y	
DMU008			Y	
DMU009			Y	
DMU010	Y			
DMU011			Y	
DMU012			Y	
DMU013	Y		Y	
DMU014	Y			
DMU015			Y	
DMU016	Y		Y	
DMU017			Y	
DMU018	Y		Y	
DMU019			Y	
DMU020			Y	
DMU021			Y	
DMU022			Y	
DMU023	Y		Y	
DMU024			Y	
DMU025			Y	
DMU026			Y	
DMU027			Y	
DMU028			Y	
DMU029			Y	
DMU030	Y		Y	
DMU031			Y	
DMU032	Y			
DMU033			Y	
DMU034			Y	
DMU035	Y			
DMU036	Y		Y	
DMU037		Y	Y	
DMU038			Y	
DMU039			Y	
DMU040			Y	
DMU041			Y	
DMU042			Y	
DMU043		Y		
DMU044	Y			
DMU045			Y	
DMU046			Y	
DMU047			Y	Y
DMU048			Y	
DMU049	Y			

References			
DMU002	DMU043	DMU083	DMU113
DMU050			Y
DMU051			Y
DMU052			Y
DMU053			Y
DMU054	Y		Y
DMU055			Y
DMU056	Y		Y
DMU057			Y
DMU058	Y		Y
DMU059			Y
DMU060	Y		Y
DMU061			Y
DMU062	Y		
DMU063	Y		
DMU064	Y		Y
DMU065			Y
DMU066	Y		Y
DMU067	Y		Y
DMU068	Y		Y
DMU069	Y		
DMU070	Y		
DMU071			Y
DMU072			Y
DMU073	Y		Y
DMU074	Y		Y
DMU075	Y		Y
DMU076			Y
DMU077			Y
DMU078	Y		
DMU079			Y
DMU080			Y
DMU081			Y
DMU082			Y
DMU083			Y
DMU084			Y
DMU085			Y
DMU086	Y		
DMU087	Y		Y
DMU088	Y		
DMU089			Y
DMU090			Y
DMU091		Y	Y
DMU092		Y	Y
DMU093	Y		Y
DMU094			Y
DMU095	Y		Y
DMU096			Y
DMU097			Y
DMU098		Y	Y

References			
DMU002	DMU043	DMU083	DMU113
DMU099			Y
DMU100	Y		
DMU101			Y
DMU102	Y		Y
DMU103			Y
DMU104			Y
DMU105			Y
DMU106			Y
DMU107			Y
DMU108	Y		Y
DMU109	Y		
DMU110			Y
DMU111			Y
DMU112			Y
DMU113			Y
DMU114			Y
DMU115	Y		
DMU116			Y
DMU117	Y		Y
DMU118			Y
DMU119			Y
DMU120	Y		
DMU121			Y
DMU122			Y
DMU123	Y		
DMU124			Y
DMU125			Y
DMU126	Y		Y
DMU127	Y		Y
DMU128			Y
DMU129	Y		
DMU130	Y		Y
DMU131	Y		Y
DMU132	Y		Y
DMU133			Y
DMU134			Y
DMU135		Y	Y
DMU136	Y		Y
DMU137			Y
DMU138	Y		Y
DMU139	Y		
DMU140		Y	Y
DMU141	Y		Y
DMU142			Y
DMU143	Y		Y
DMU144			Y
DMU145	Y		Y
DMU146			Y

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 1)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
1	Electrical and electronics	DMU001	1532098.8	0.9	858666.67	27600000	44466666.67	10.1	81941333.33	0.0517	136
2	Creative industries	DMU002	64400000	10.8	9200000	880000000	–	–	–	1.0000	1
3	Chemistry and materials	DMU003	24150000	4.5	3450000	330000000	67850000	1.8	5750000	0.5389	12
4	Chemistry and materials	DMU004	10222222	0.9	5724444.4	220000000	109377777.8	2.7	3475555.56	0.3817	20
5	ICT	DMU005	6580555.6	0.9	2006111.1	110000000	48619444.44	5.4	25593888.89	0.1364	88
6	Electrical and electronics	DMU006	8765555.6	0.9	4237111.1	176000000	64834444.44	2.7	23362999.99	0.2130	52
7	Chemistry and materials	DMU007	10222222	0.9	5724444.4	220000000	72577777.78	12.6	86275555.56	0.1028	108
8	Health	DMU008	7666666.7	0.9	4293333.3	165000000	42933333.33	2.7	50906666.67	0.1952	60
9	Mechanics and machine tools	DMU009	6133333.3	0.9	3434666.7	132000000	67466666.67	0.9	70165333.33	0.2565	45
10	Electrical and electronics	DMU010	3220000	0.9	460000	44000000	51980000	3.6	17940000	0.1154	98
11	Electrical and electronics	DMU011	39866666	3.6	22325333	858000000	33733333.33	6.3	437674666.7	0.3804	21
12	Health	DMU012	9200000	0.9	5152000	198000000	73600000	3.6	80408000	0.1513	80
13	Mechanics and machine tools	DMU013	5488055.6	0.9	890611.11	77000000	86511944.44	1.8	31309388.89	0.1712	74
14	ICT	DMU014	2415000	0.9	345000	33000000	43585000	10.8	8855000	0.0679	129
15	Chemistry and materials	DMU015	17377778	1.8	9731555.6	374000000	33222222.22	3.6	82268444.44	0.3121	30
16	Electrical and electronics	DMU016	27025000	2.7	13455000	550000000	64975000	13.5	14145000	0.3784	22
17	Electrical and electronics	DMU017	1277777.8	0.9	715555.56	27500000	81522222.22	3.6	54484444.44	0.0930	116
18	Electrical and electronics	DMU018	5852222.2	0.9	1262444.4	88000000	76947777.78	5.4	35537555.56	0.1009	110

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 2)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
19	Agriculture and Food industry	DMU019	51111111	4.5	28622222	1100000000	40888888.89	0.9	44977777.78	0.7099	9
20	Chemistry and materials	DMU020	2044444.4	0.9	1144888.9	44000000	89955555.56	4.5	10557511.16	0.0814	118
21	Information and Communications Technology	DMU021	23766667	2.7	13309333	511500000	68233333.33	6.3	12469066.67	0.2668	40
22	Building industry	DMU022	27600000	2.7	15456000	594000000	64400000	21.6	16854400.00	0.2020	54
23	Agriculture and Food industry	DMU023	47469444	4.5	24903889	990000000	7730555.556	1.8	2696111.111	0.9016	3
24	Mechanics and machine tools	DMU024	2044444.4	1.8	11448889	440000000	43955555.56	4.5	26455111.16	0.2630	42
25	Chemistry and materials	DMU025	11755556	1.8	6583111.1	253000000	34244444.44	4.5	39416888.89	0.2792	37
26	Health	DMU026	7155555.6	0.9	4007111.1	154000000	34244444.44	2.7	60392888.89	0.1980	56
27	Information and Communications Technology	DMU027	10222222	0.9	5724444.4	220000000	44977777.78	4.5	77075555.56	0.1716	73
28	Information and Communications Technology	DMU028	2044444.4	1.8	11448889	440000000	25555555.56	1.8	25351111.16	0.4816	16
29	Agriculture and Food industry	DMU029	25555556	2.7	14311111	550000000	20444444.44	11.7	68488888.89	0.3630	23
30	Chemistry and materials	DMU030	23674667	2.7	10034133	448800000	68325333.33	7.2	17565866.67	0.3495	25
31	Chemistry and materials	DMU031	1533333.3	0.9	858666.67	33000000	72066666.67	4.5	72741333.33	0.0813	119
32	Mechanics and machine tools	DMU032	3220000	0.9	460000	44000000	70380000	2.7	27140000	0.1265	89
33	Information and Communications Technology	DMU033	1533333.3	0.9	858666.67	33000000	35266666.67	26.1	72741333.33	0.0354	138
34	Information and Communications Technology	DMU034	46000000	4.5	25760000	990000000	36800000	18.0	43424000	0.3246	28

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 3)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
35	Creative industries	DMU035	966000.0	0.9	138000.0	13200000	35834000.0	4.5	1242000.0	0.1194	99
36	Creative industries	DMU036	6580555.6	0.9	2006111.1	110000000	48619444.44	2.7	7193888.889	0.2398	47
37	Creative industries	DMU037	9711111.1	0.9	68795556	275000000	45488888.89	3.6	71320444.44	0.1895	58
38	Agriculture and Food industry	DMU038	10222222	0.9	5724444.4	220000000	72577777.78	12.6	86275555.56	0.1028	108
39	Mechanics and machine tools	DMU039	17888889	1.8	10017778	385000000	74111111.11	6.3	13902222.22	0.1973	57
40	Agriculture and Food industry	DMU040	6644444.4	0.9	3720888.9	143000000	66955555.56	5.4	59427911.16	0.0976	105
41	Information and Communications Technology	DMU041	18400000	1.8	10304000	396000000	18400000.0	6.3	44969600.0	0.3048	32
42	Agriculture and Food industry	DMU042	9200000.0	0.9	5152000.0	198000000	64400000.0	2.7	13284800.0	0.1684	71
43	Information and Communications Technology	DMU043	55200000	5.4	791200000	198000000	–	–	–	1.0000	1
44	Chemistry and materials	DMU044	2415000.0	0.9	345000.0	33000000	52785000.0	3.6	5175000.0	0.1250	87
45	Agriculture and Food industry	DMU045	40888889	3.6	22897778	880000000	51111111.11	2.7	37638222.22	0.4383	19
46	Building industry	DMU046	7666666.7	0.9	4293333.3	165000000	84333333.33	10.8	65626666.67	0.0905	112
47	Agriculture and Food industry	DMU047	16457778	0.9	13779356	264000000	66342222.22	2.7	9662044.444	0.2343	49
48	Electrical and electronics	DMU048	46000000	4.5	25760000	990000000	27600000.0	2.7	38824000.0	0.5029	15
49	Mechanics and machine tools	DMU049	2415000.0	0.9	345000.0	33000000	89585000.0	6.3	45655000.0	0.0649	132
50	Health	DMU050	15333333	1.8	8586666.7	330000000	39866666.67	3.6	12941333.33	0.2755	38
51	Chemistry and materials	DMU051	7155555.6	0.9	4007111.1	154000000	84844444.44	1.8	27199288.89	0.1741	69
52	Mechanics and machine tools	DMU052	10222222.2	0.9	572444.4	22000000	72577777.78	2.7	18342666.67	0.1090	102
53	Energy	DMU053	7666666.7	0.9	4293333.3	165000000	75133333.33	1.8	60106666.67	0.2012	55

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 4)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
54	Energy	DMU054	6580555.6	0.9	2006111.1	110000000	39419444.44	2.7	16393888.89	0.2049	53
55	Information and Communications Technology	DMU055	–	–	–	–	–	–	–	0.1875	61
56	Agriculture and Food industry	DMU056	15333333	1.8	8586666.7	330000000	49066666.67	49.5	37413333.33	–	–
57	Energy	DMU057	6580555.6	0.9	2006111.1	110000000	131419444.4	3.6	43993888.89	0.1190	100
58	Agriculture and Food industry	DMU058	38333333	3.6	21466667	825000000	90466666.67	5.4	180013333.3	0.3285	27
59	Agriculture and Food industry	DMU059	6580555.6	0.9	2006111.1	110000000	113019444.4	1.8	25593888.89	0.1881	62
60	Electrical and electronics	DMU060	10222222	0.9	5724444.4	220000000	155377777.8	6.3	67875555.56	0.1081	103
61	Mechanics and machine tools	DMU061	7308888.9	0.9	2749777.8	132000000	84691111.11	9.0	24850222.22	0.1103	101
62	Information and Communications Technology	DMU062	7666666.7	0.9	4293333.3	165000000	111933333.3	3.6	87706666.67	0.1269	90
63	Information and Communications Technology	DMU063	4025000	0.9	575000	55000000	133975000	4.5	27025000	0.0884	114
64	Chemistry and materials	DMU064	4025000	0.9	575000	55000000	83375000	7.2	8625000	0.0898	113
65	Agriculture and Food industry	DMU065	6580555.6	0.9	2006111.1	110000000	103819444.4	1.8	25593888.89	0.1902	60
66	Information and Communications Technology	DMU066	7666666.7	0.9	4293333.3	165000000	84333333.33	1.8	170506666.7	0.1802	66
67	Building industry	DMU067	5852222.2	0.9	1262444.4	88000000	86147777.78	3.6	35537555.56	0.1217	97
68	Information and Communications Technology	DMU068	8401388.9	0.9	3865277.8	165000000	111198611.1	9.9	32934777.78	0.1057	104
69	Information and Communications Technology	DMU069	7308888.9	0.9	2749777.8	132000000	84691111.11	5.4	43250222.22	0.1153	99
70	Creative industries	DMU070	36225000	6.3	5175000	495000000	46575000	–	4025000	0.7333	6

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 5)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
71	Health	DMU071	14566667	1.8	8157333.3	313500000	109633333.3	5.4	106842666.7	0.1792	65
72	Health	DMU072	13800000	1.8	7728000	297000000	55200000	3.6	38272000	0.2869	39
73	Electrical and electronics	DMU073	14981944	1.8	5871394.4	275000000	72417944.44	4.5	12528611.11	0.3174	29
74	Health	DMU074	6216388.9	0.9	1634278.9	99000000	67383588.89	9.0	31485722.22	0.0919	111
75	Information and Communications Technology	DMU075	14981944	1.8	5871394.4	275000000	49417944.44	4.5	30928611.11	0.2779	37
76	Information and Communications Technology	DMU076	4600000	0.9	2576000	99000000	73600000	8.1	52624000	0.0841	116
77	Electrical and electronics	DMU077	7411111.1	0.9	4150222.2	159500000	70788888.89	1.8	55649777.78	0.2034	54
78	Mechanics and machine tools	DMU078	2898000	0.9	4140000	39600000	61502000	8.1	16146000	0.0696	128
79	Health	DMU079	5111111.1	0.9	2862222.2	110000000	31688888.89	0.9	24737777.78	0.3046	33
80	Health	DMU080	15333333	1.8	8586666.7	330000000	58266666.67	4.5	37413333.33	0.2789	36
81	Chemistry and materials	DMU081	1022222.2	0.9	5724444.4	220000000	72577777.78	1.8	86275555.56	0.2122	51
82	Electrical and electronics	DMU082	5111111.1	4.5	2862222.2	110000000	13288888.89	0.9	15537777.78	0.6536	8
83	Health	DMU083	82800000	1.8	92000000	88000000	–	–	–	1.0000	1
84	Information and Communications Technology	DMU084	5111111.1	0.9	2862222.2	110000000	40888888.89	6.3	43137777.78	0.1221	96
85	Information and Communications Technology	DMU085	25555556	2.7	14311111	550000000	57244444.44	15.3	16968888.89	0.2196	48
86	Mechanics and machine tools	DMU086	2898000	0.9	4140000	39600000	107502000	1.8	8786000	0.1654	67
87	Mechanics and machine tools	DMU087	47469444	4.5	24903889	99000000	26130555.56	0.9	2696111.111	0.8729	4
88	Creative industries	DMU088	2415000	0.9	3450000	33000000	80385000	7.2	18055000	0.0651	131
89	Agriculture and Food industry	DMU089	3322222.2	3.6	1860444.4	71500000	58777777.78	7.2	11939555.56	0.3390	26

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 6)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
90	Agriculture and Food industry	DMU090	51111111	4.5	28622222	1100000000	13288888.89	15537777.78	–	0.7147	7
91	Chemistry and materials	DMU091	61154444	3.6	49076889	1023000000	49245555.56	41092333.33	–	0.6089	11
92	Information and Communications Technology	DMU092	36033333	1.8	31586667	550000000	28366666.67	20761333.33	–	0.6203	10
93	Information and Communications Technology	DMU093	6580555.6	0.9	2006111.1	110000000	71619444.44	16393888.89	–	0.1469	84
94	Information and Communications Technology	DMU094	25555556	2.7	14311111	550000000	20444444.44	50088888.89	–	0.4074	20
95	Mechanics and machine tools	DMU095	14253611	1.8	5127712.2	253000000	59346388.89	13272277.78	–	0.3295	31
96	Chemistry and materials	DMU096	7666666.7	0.9	4293333.3	165000000	84333333.33	27170666.67	–	0.1425	81
97	Energy	DMU097	12777778	1.8	7155555.6	275000000	70022222.22	9404444.44	–	0.1736	64
98	Electrical and electronics	DMU098	9302222.2	2.7	9772444.4	1100000000	17377777.78	17827555.56	–	0.8054	5
99	Electrical and electronics	DMU099	15333333	1.8	8586666.7	330000000	10426666.67	12941333.33	–	0.2145	50
100	Creative industries	DMU100	4025000	0.9	575000	550000000	87975000	45425000	–	0.1594	70
101	Information and Communications Technology	DMU101	12777778	1.8	7155555.6	275000000	10682222.22	84844444.44	–	0.1662	68
102	Chemistry and materials	DMU102	6580555.6	0.9	2006111.1	110000000	17741944.44	43993888.89	–	0.1006	107
103	Information and Communications Technology	DMU103	17888889	1.8	10017778	385000000	74111111.11	12798222.22	–	0.2456	43
104	Building industry	DMU104	51111111	4.5	28622222	1100000000	11448888.89	20137777.78	–	0.2897	35
105	Energy	DMU105	10222222	0.9	5724444.4	220000000	81777777.78	67875555.56	–	0.1795	63
106	Mechanics and machine tools	DMU106	3577777.8	0.9	2003555.6	770000000	42422222.22	43996444.44	–	0.1081	105

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 7)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
107	Information and Communications Technology	DMU107	1328888.9	0.9	744088.9	28600000	63071111.11	20.7	72855777.78	0.0295	140
108	Mechanics and machine tools	DMU108	6580555.6	0.9	2006111.1	110000000	103819444.4	8.1	16393888.89	0.1098	106
109	Creative industries	DMU109	20527500	3.6	2932500	280500000	71472500	1.8	1667750	0.5600	13
110	Agriculture and Food industry	DMU110	2453333.3	0.9	1373866.7	52800000	80346666.67	3.6	90626133.33	0.0999	109
111	Electrical and electronics	DMU111	26680000	2.7	14940800	574200000	37720000	0.9	77059200	0.4864	17
112	Chemistry and materials	DMU112	5111111.1	0.9	2862222.2	110000000	68488888.89	4.5	43137777.78	0.1221	96
113	Electrical and electronics	DMU113	92000000	8.1	51520000	198000000	–	–	–	1.0000	1
114	Health	DMU114	2300000	0.9	1288000	49500000	85100000	3.6	27471200	0.0946	115
115	Mechanics and machine tools	DMU115	4830000	0.9	690000	66000000	9637000	1.8	6675000	0.1941	59
116	Information and Communications Technology	DMU116	2044444.4	0.9	1144888.9	44000000	34755555.56	5.4	31055111.11	0.0956	114
117	Information and Communications Technology	DMU117	27025000	2.7	13455000	550000000	46575000	21.6	14145000	0.3784	22
118	Health	DMU118	30666667	2.7	17173333	660000000	52133333.33	5.4	35082666.67	0.3001	30
119	Health	DMU119	10222222	0.9	5724444.4	220000000	77177777.78	4.5	63275555.56	0.1500	79
120	Agriculture and Food industry	DMU120	2415000	0.9	345000	33000000	66585000	4.5	8855000	0.0977	110
121	Information and Communications Technology	DMU121	15333333	1.8	8586666.7	330000000	44466666.67	9.0	12941333.33	0.1980	56
122	Building industry	DMU122	10222222	0.9	5724444.4	220000000	44977777.78	2.7	13227555.56	0.1949	58
123	Chemistry and materials	DMU123	2415000	0.9	345000	33000000	61985000	5.4	1495000	0.1509	78
124	Information and Communications Technology	DMU124	10222222	0.9	5724444.4	220000000	21977777.78	1.8	12675555.56	0.3927	21

Table 11: Appendix. Results of the Weighted SBM model for Iranian TBFs (Part 8)

NO	Sector	Code	Improvement				Slacks			Weighted SBM Eff.	New Rank
			I_1	I_2	I_3	R_1	I_1	I_2	I_3		
125	Information and Communications Technology	DMU125	1277777.8	0.9	715555.6	27500000	35522222.22	8.1	26884444.44	0.0655	130
126	Mechanics and machine tools	DMU126	16802778	1.8	7730555.6	330000000	121197222.2	2.7	10669444.44	0.3860	24
127	Mechanics and machine tools	DMU127	6580555.6	0.9	2006111.1	110000000	39419444.44	4.5	2593888.89	0.3052	32
128	Health	DMU128	51111111	4.5	28622222	1100000000	63888888.89	3.6	339377777.8	0.3952	23
129	Agriculture and Food industry	DMU129	4830000	0.9	690000	66000000	105570000	12.6	8515000	0.0759	125
130	Agriculture and Food industry	DMU130	6580555.6	0.9	2006111.1	110000000	108419444.4	3.6	20073888.89	0.1423	82
131	Agriculture and Food industry	DMU131	78136111	7.2	42077222	1650000000	13863888.89		3922777.78	1.0000	1
132	Information and Communications Technology	DMU132	27025000	2.7	13455000	550000000	101775000		18745000	0.6249	12
133	Creative industries	DMU133	7666666.7	0.9	4293333.3	165000000	130333333.3	0.9	27170666.67	0.2338	44
134	Chemistry and materials	DMU134	46000000	4.5	25760000	990000000	46000000	23.4	268640000	0.3069	31
135	Chemistry and materials	DMU135	72066667	3.6	63173333	1100000000	65933333.33		120826666.7	0.6841	9
136	Mechanics and machine tools	DMU136	6944722.2	0.9	2377944.4	121000000	112655277.8	9.0	34422055.56	0.0874	118
137	Health	DMU137	15333333	1.8	8586666.7	330000000	49066666.67	16.2	65013333.33	0.1862	61
138	Health	DMU138	6580555.6	0.9	2006111.1	110000000	149819444.4	2.7	16393888.89	0.1639	69
139	Chemistry and materials	DMU139	4025000	0.9	575000	55000000	161575000	2.7	91425000	0.1148	95
140	Health	DMU140	25811111	0.9	25862222	330000000	121388888.9	1.8	66137777.78	0.3236	28
141	Electrical and electronics	DMU141	7308888.9	0.9	2749777.8	132000000	139891111.1	4.5	52450222.22	0.1089	104
142	Mechanics and machine tools	DMU142	5111111.1	0.9	2862222.2	110000000	142088888.9	14.4	181137777.8	0.0447	137
143	Electrical and electronics	DMU143	8401388.9	0.9	3865277.8	165000000	193998611.1	5.4	106535555.6	0.0897	117
144	Health	DMU144	20444444	1.8	11448889	440000000	163555555.6	8.1	172551111.1	0.1456	77
145	Health	DMU145	6580555.6	0.9	2006111.1	110000000	122219444.4	3.6	25593888.89	0.1324	86
146	Electrical and electronics	DMU146	10222222	0.9	5724444.4	220000000	127777777.8	4.5	86275555.56	0.1240	93

Table 12: Appendix. Introducing benchmark units for inefficient units to achieve optimal efficiency levels (Weighted SBM Model) (Part 1)

References					References					References				
DMU002	DMU043	DMU083	DMU113	DMU131	DMU002	DMU043	DMU083	DMU113	DMU131	DMU002	DMU043	DMU083	DMU113	DMU131
DMU001				Y	DMU050				Y	DMU099				Y
DMU002	Y				DMU051				Y	DMU100	Y			
DMU003	Y				DMU052				Y	DMU101				Y
DMU004				Y	DMU053				Y	DMU102	Y			Y
DMU005	Y			Y	DMU054	Y			Y	DMU103				Y
DMU006	Y			Y	DMU055				Y	DMU104				Y
DMU007				Y	DMU056	Y			Y	DMU105				Y
DMU008				Y	DMU057				Y	DMU106				Y
DMU009				Y	DMU058	Y			Y	DMU107				Y
DMU010	Y				DMU059				Y	DMU108	Y			Y
DMU011				Y	DMU060	Y			Y	DMU109	Y			
DMU012				Y	DMU061				Y	DMU110				Y
DMU013	Y			Y	DMU062	Y				DMU111				Y
DMU014	Y				DMU063	Y				DMU112				Y
DMU015				Y	DMU064	Y			Y	DMU113			Y	
DMU016	Y			Y	DMU065				Y	DMU114				Y
DMU017				Y	DMU066	Y			Y	DMU115	Y			
DMU018	Y			Y	DMU067	Y			Y	DMU116				Y
DMU019				Y	DMU068	Y			Y	DMU117	Y			Y
DMU020				Y	DMU069	Y				DMU118				Y
DMU021				Y	DMU070	Y				DMU119				Y
DMU022				Y	DMU071				Y	DMU120	Y			
DMU023	Y			Y	DMU072				Y	DMU121				Y
DMU024				Y	DMU073	Y			Y	DMU122				Y
DMU025				Y	DMU074	Y			Y	DMU123	Y			
DMU026				Y	DMU075	Y			Y	DMU124				Y

Table 12: Appendix. Introducing benchmark units for inefficient units to achieve optimal efficiency levels (Weighted SBM Model) (Part 2)

References						References					References				
DMU002	DMU043	DMU083	DMU113	DMU131		DMU002	DMU043	DMU083	DMU113	DMU131	DMU002	DMU043	DMU083	DMU113	DMU131
DMU027				Y		DMU076				Y	DMU125				Y
DMU028				Y		DMU077				Y	DMU126	Y			Y
DMU029				Y		DMU078	Y				DMU127	Y			Y
DMU030	Y			Y		DMU079				Y	DMU128				Y
DMU031				Y		DMU080				Y	DMU129	Y			
DMU032	Y					DMU081				Y	DMU130	Y			Y
DMU033				Y		DMU082				Y	DMU131	Y			Y
DMU034				Y		DMU083			Y		DMU132	Y			Y
DMU035	Y					DMU084				Y	DMU133				Y
DMU036	Y			Y		DMU085				Y	DMU134				Y
DMU037		Y		Y		DMU086	Y				DMU135		Y		Y
DMU038				Y		DMU087	Y			Y	DMU136	Y			Y
DMU039				Y		DMU088	Y				DMU137				Y
DMU040				Y		DMU089				Y	DMU138	Y			Y
DMU041				Y		DMU090				Y	DMU139	Y			
DMU042				Y		DMU091		Y		Y	DMU140		Y		Y
DMU043		Y				DMU092		Y		Y	DMU141	Y			Y
DMU044	Y					DMU093	Y			Y	DMU142				Y
DMU045				Y		DMU094				Y	DMU143	Y			Y
DMU046				Y		DMU095	Y			Y	DMU144				Y
DMU047				Y	Y	DMU096				Y	DMU145	Y			Y
DMU048				Y		DMU097				Y	DMU146				Y
DMU049	Y					DMU098		Y		Y					

Declarations

Availability of Supporting Data

All data generated or analyzed during this study are included in this published paper.

Funding

The authors conducted this research without any funding, grants, or support.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Author Contributions

Zahra Mohammadhashemi: Conceptualization, Methodology, Writing – Original Draft, Supervision, Project Administration. Khatere Ghorbani-Moghadam: Formal Analysis, Data Curation, Software, Validation. Safora Allahy: Investigation, Data Collection, Writing – Review & Editing.

Artificial Intelligence Statement

Artificial intelligence (AI) tools, including large language models, were used solely for language editing and improving readability. AI tools were not used for generating ideas, performing analyses, interpreting results, or writing the scientific content. All scientific conclusions and intellectual contributions were made exclusively by the authors.

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References

[1] Amini, A., Bonyadi Naeini, A., Mohamadi, M., Ahadzadeh Namin, M. (2016). "Performance evaluation of management of technology and innovation in two stages of enablers and results using data envelopment analysis". *Journal of Technology Development Management*, 4(3), 33-68, doi:https://doi:10.22104/jtdm.2017.2120.1737.

[2] Banker, R.D., Charnes, A., Cooper, W.W. (1984). "Some models for estimating technical and scale inefficiencies in data envelopment analysis". *Management Science*, 30(9), 1078-1092, doi:https://doi:10.1287/mnsc.30.9.1078.

[3] Bogetoft, P., Otto, L. (2011). "Benchmarking with DEA, SFA, and R". *Springer, New York, NY*. doi:https://doi.org/10.1007/978-1-4419-7961-2.

[4] Charnes, A., Cooper, W.W. (1985). "Programming with linear fractional functionals". *Naval Research Logistics Quarterly*, 9(3-4), 181-186, doi:https://doi.org/10.1002/nav.3800090303.

[5] Charnes, A., Cooper, W.W., Rhodes, E. (1978). "Measuring the efficiency of decision-making units". *European Journal of Operational Research*, 2(6), 429-444, doi:https://doi.org/10.1016/0377-2217(78)90138-8.

[6] Charnes, A., Cooper, W.W., Golany, B., Seiford, L., Stutz, J. (1985). "Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions". *Journal of Econometrics*, 30(1-2), 91-107, doi:https://doi.org/10.1016/0304-4076(85)90133-2.

[7] Chen, G., Breedlove, J. (2020). "The effect of innovation-driven policy on innovation efficiency: Based on the listed sports firms on Chinese New Third Board". *International Journal of Sports Marketing and Sponsorship*, 21(4), 735-755, doi:https://doi.org/10.1108/IJSMS-12-2019-0136.

[8] Chen, H., Xu, R., Feng, Zh. (2013). "Evaluation of technological innovation efficiency in Chinese high-tech industry: Two-stage relational DEA". *Information Technology Journal*, 12(15), 3169-3173, doi:https://doi.org/10.3923/itj.2013.3169.3173.

[9] Chen, C.T., Chien, C.F., Lin, M.H., Wang, J.T. (2004). "Using DEA to evaluate R&D performance of the computers and peripherals firms in Taiwan". *International Journal of Business*, 9(4), 347.

[10] Chipman, J.S. (1957). "Three essays on the state of economic science, Tjalling C. Koopmans. New York: McGraw-Hill Book Company, Inc., 1957. Pp. xii, 231. $ 6.50". *American Journal of Agricultural Economics*, 41(2), 447-449, doi:https://doi.org/10.2307/1235177.

[11] Cockayne, D. (2019). "What is a startup firm? A methodological and epistemological investigation into research objects in economic geography". *Geoforum*, 107, 77-87, doi:https://doi.org/10.1016/j.geoforum.2019.10.009.

[12] Cook, W.D., Seiford, L.M. (2009). "Data envelopment analysis (DEA) – Thirty years on". *European Journal of Operational Research*, 192(1), 1-17, doi:https://doi.org/10.1016/j.ejor.2008.01.032.

[13] Cooper, W.W., Seiford, L.M., Zhu, J. (2011). "Data envelopment analysis: History, models, and interpretations". In: *Cooper, W., Seiford, L., Zhu, J. (eds) Handbook on Data Envelopment Analysis. International Series in Operations Research & Management Science, vol 164. Springer, Boston, MA*, doi:https://doi.org/10.1007/978-1-4419-6151-8_1.

[14] Debreu, G. (1951). "The coefficient of resource utilization". *Econometrica*, 19, 273-292, doi:http://dx.doi.org/10.2307/1906814.

[15] Du, J., Lin, F., Chen, J., Morris, S. C., Nie, C. (2012). "Numerical study on the influence mechanism of inlet distortion on the stall margin in a transonic axial rotor". *Journal of Thermal Science*, 21(3), 209–214, doi:https://doi.org/10.1007/s11630-012-0537-2.

[16] Erena, O.T., Kalko, M.M., Debele, S.A. (2021). "Technical efficiency, technological progress and productivity growth of large and medium manufacturing industries in Ethiopia: A data envelopment analysis". *Cogent Economics & Finance*, 9(1), doi:https://doi.org/10.1080/23322039.2021.1997160.

[17] Färe, R.G., Knox Lovell, C.A. (2005). "Measuring the technical efficiency of production". *Journal of Economic Theory*, 19(1), 150-162. 16, doi:https://doi.org/10.1016/0022-0531(78)90060-1.

[18] Farrell, M.J. (1957). "The measurement of productive efficiency". *Journal of the Royal Statistical Society*, 120(3), 253–290, doi:https://doi.org/10.2307/2343100.Accessed31Oct.2025.

[19] Fukugawa, N. (2006). "Determining factors in the innovation of small firm networks: A case of cross-industry groups in Japan". *Small Business Economics*, 27, 181-193, doi:https://doi.org/10.1007/s11187-006-0010-2.

[20] Grilo, A., Santos, J. (2015). "Measuring efficiency and productivity growth of new technology-based firms in business incubators: The Portuguese case study of Madan Parque". *The Scientific World Journal*, doi:https://doi.org/10.1155/2015/936252.

[21] Grinstein, A., Goldman, A. (2006). "Characterizing the technology firm: An exploratory study". *Research Policy*, 35(1), 121-143, doi:http://dx.doi.org/10.1016/j.respol.2005.09.003.

[22] Grosskopf, S. (1993). "Efficiency and Productivity". In *Fried HO and SS Schmidt (eds.) The Measurement of Productive Efficiency: Techniques and Applications, Oxford, U.K.*: 160-194.

[23] Johnson, A.L., McGinnis, L.F. (2008). "Outlier detection in two-stage semiparametric DEA models". *European Journal of Operational Research*, 187(2), 629-635, doi:https://doi.org/10.1016/j.ejor.2007.03.041.

[24] Khayatian, M., Tabatabaiyan, H., Elyasi, M. (2019). "Analysis of the factors influencing the growth and sustainability of Knowledge-based firms in Iran". *Journal of Innovation and Value Creation*, 3(6), 57-74, doi:http://journalie.ir/en/Article/345.

[25] Kim, C., Shin, W.S. (2019). "Does information from the higher education and R&D institutes improve the innovation efficiency of logistic firms?". *The Asian Journal of Shipping and Logistics*, 35(1), 70-76, doi:https://doi.org/10.1016/j.ajsl.2019.03.010.

[26] Lindelof, P., Lofsten, H. (2003). "Science park location and new technology-based firms in Sweden-implications for strategy and performance". *Small Business Economics*, 20(3), 245-258, doi:https://doi.org/10.1023/A:1022861823493.

[27] Lu, Y.H., Shen, C.C., Ting, C.T., Wang, C.H. (2010). "Research and development in productivity measurement: An empirical investigation of the high technology industry". *African Journal of Business Management*, 4(13), 2871-2884, doi:https://doi.org/10.5897/AJBM.9000491.

[28] Maine, E.M., Shapiro, D.M., Vining, A.R. (2010). "The role of clustering in the growth of new technology-based firms". *Small Business Economics*, 34, 127-146, doi:http://dx.doi.org/10.1007/s11187-008-9104-3.

[29] Marwick, A.E. (2013). "Status update: Celebrity, publicity, and branding in the social media age". *Yale University Press*, http://www.jstor.org/stable/j.ctt5vkzxr.

[30] Pourmahmoud, J., Abbasi, A., Ghaffari-Hadigheh, A. (2025). "Network data envelopment analysis and uncertainty in decision-making: A three-stage model based on Liu's uncertainty theory". *Control and Optimization in Applied Mathematics*, doi:https://doi.org/10.30473/coam.2025.73893.1293.

[31] Rojas, F., Huergo, E. (2016). "Characteristics of entrepreneurs and public support for NTBFs". *Small Business Economics*, 47(2), 363-382, doi:https://doi.org/10.1007/s11187-016-9718-9.

[32] Mohammadhashemi, Z. (2017). "The relationship among university, industry and government with emphasis on the role of intermediary institutions. Case Study: Coordination centers of Knowledge, Industry and Markets". *Rahyaft*, 27(66), 75-88, doi:https://dor.isc.ac/dor/20.1001.1.10272690.1396.27.66.6.6

[33] Stemler, S. (2000). "An overview of content analysis". *Practical Assessment, Research, and Evaluation*, 7(1), 17, doi:https://doi.org/10.7275/z6fm-2e34.

[34] Sutopo, W., Khofiyah, N.A., Hisjam, M., Ma'aram, A. (2022). "Performance efficiency measurement model development of a technology transfer office (TTO) to accelerate technology commercialization in universities". *Applied System Innovation*, 5(1), 21, doi:https://doi.org/10.3390/asi5010021.

[35] Tone, K. (2001). "A slacks-based measure of efficiency in data envelopment analysis". *European Journal of Operational Research*, 130(3), 498-509, doi:https://doi.org/10.1016/S0377-2217(99)00407-5.

[36] Tone, K., Toloo, M., Izadikhah, M. (2020). "A modified slacks-based measure of efficiency in data envelopment analysis". *European Journal of Operational Research*, 287(2), 560-571, doi:https://doi.org/10.1016/j.ejor.2020.04.019.

[37] Van Elk, R., Ter Weel, B., van der Wiel, K., Wouterse, B. (2019). "Estimating the returns to public RD investments: Evidence from production function models". *De Economist*, 167(1), 45–87, doi:https://doi.org/10.1007/s10645-019-09331-3.

[38] Yaghoubi, M., Teymourzadeh, E., Bahadori, M., Ghardashi, F. (2017). "Conceptual model of innovation capability in industrial and academic research centers: A systematic review". *Interdisciplinary Journal of Management Studies*, 10(3), 609-640, doi:https://doi.org/10.22059/ijms.2017.238379.672756.

[39] Zhu, J. (2014). "Quantitative models for performance evaluation and benchmarking". *Springer Cham, Switzerland*, doi:https://doi.org/10.1007/978-3-319-06647-9.