

RESEARCH ARTICLE

Theoretical Aspects of Assessing the Operational Efficiency of The Grain Farming Sector Under Global Climate Change

Mirzayev Bobur Baxodirovich

Student, National Research University "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers", Uzbekistan

VOLUME: Vol.06 Issue06 2026

PAGE: 26-31

Copyright © 2026 Journal of Management and Economics, this is an open-access article distributed under the terms of the Creative Commons Attribution-Noncommercial-Share Alike 4.0 International License. Licensed under Creative Commons License a Creative Commons Attribution 4.0 International License.

Abstract

This article presents a comparative theoretical examination of five leading methodologies employed in assessing the operational efficiency of the grain farming sector under conditions of global climate change: Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Total Factor Productivity (TFP), Ricardian Analysis, and the Computable General Equilibrium model (CGE). The study employs a theoretical-synthetic approach, utilizing a systematic literature review and a multi-criteria evaluation matrix to compare the methodologies in terms of their effectiveness under conditions of climate variability, data requirements, level of analysis, and policy relevance. The research finds that the direct application of standard methodologies to Uzbekistan's conditions - without appropriate adaptation - may yield misleading conclusions due to the country's distinctive ecological and institutional characteristics, including the Aral Sea crisis, water scarcity, soil degradation, and small-scale farm structures. Drawing on the experiences of Kazakhstan, India, and Turkey, the study recommends a three-tier methodological framework for Uzbekistan: descriptive analysis with partial factor productivity; climate-augmented SFA and meta-frontier analysis for farm-level efficiency assessment; and dynamic productivity change measurement using the Malmquist index. The proposed framework enables a unified assessment of efficiency from the farm level to the macroeconomic level and serves as a critical methodological foundation for substantiating food security policy.

KEYWORDS

Grain farming efficiency, climate change, data envelopment analysis, stochastic frontier analysis, total factor productivity, Ricardian analysis, computable general equilibrium model, Malmquist index, water scarcity, Aral Sea crisis, soil degradation, technical efficiency, methodological framework, Uzbekistan agriculture.

INTRODUCTION

The question of assessing the efficiency of grain production in global agriculture has never been more urgently relevant. According to data from the United Nations Food and Agriculture Organization (FAO), the world's population is projected to reach 9.7 billion by 2050. This level of population growth will necessitate an increase in food demand by at least 50 percent. However, global climate change is severely narrowing the possibilities for meeting this demand, posing

new threats to agricultural productivity (IPCC, 2022).

The impact of climate change on grain production is multifaceted. Rising temperatures, shifts in precipitation patterns, and the increasingly frequent recurrence of extreme weather events such as droughts and heat waves are not only reducing grain crop yields but also diminishing resource use efficiency. Research by Schlenker and Roberts (2009)

demonstrated that once temperatures exceed a certain optimal threshold, grain crop yields decline in a nonlinear fashion. This situation places on the agenda the problem of the inadequacy of conventional efficiency assessment methods under conditions of climate variability.

For Uzbekistan, this problem is particularly acute. Ecological crises such as the desiccation of the Aral Sea, soil salinization, water scarcity, and desertification are placing the country's grain farming sector under dual pressure: on one hand, natural resources are diminishing; on the other, climatic stress is intensifying (UNDP, 2019). In such complex circumstances, the question of which methodological approaches can accurately and fairly assess the activities of grain producers warrants dedicated scientific investigation.

Several major methodological currents exist in the current scholarly literature for assessing grain farming efficiency: among non-parametric methods, Data Envelopment Analysis (DEA) and the Malmquist Productivity Index; among parametric methods, Stochastic Frontier Analysis (SFA); as macroeconomic approaches, Total Factor Productivity (TFP); and among climate-economic approaches, the Ricardian approach and the Computable General Equilibrium model (CGE). However, the comparative performance of these methods under conditions of climate change and their suitability for Uzbekistan have not yet been subjected to sufficiently rigorous comparative analysis.

LITERATURE REVIEW AND METHODOLOGY

The modern theory of efficiency assessment is grounded in the foundation laid by Farrell (1957). He was the first to define the concept of technical efficiency precisely and proposed a geometric method for its measurement: the degree to which the maximum possible output can be produced given a set of input factors. The Farrell approach was subsequently substantially developed by Charnes, Cooper, and Rhodes (1978). They were the first to develop a linear programming-based DEA model for multiple inputs and multiple outputs, and introduced the concept of the Decision Making Unit (DMU). Although this methodology was initially applied in the banking and manufacturing sectors, it was later widely adopted in agriculture, particularly in grain production. Seiford and Thrall (1990) expanded the theoretical foundations of DEA; Banker, Charnes, and Cooper (1984) introduced the Variable Returns to Scale (VRS) model. This model is especially significant for small farm enterprises, as it eliminates the error of

inappropriately comparing farms of different sizes.

The formation of SFA as an independent methodological direction is associated with the foundational article by Aigner, Lovell, and Schmidt (1977). They, simultaneously with Meeusen and van den Broeck (1977), proposed the incorporation of a composite error term into the production function: one component representing random noise (v) and the other a one-sided inefficiency term (u). This approach proved revolutionary in agriculture, as it enabled the separation of random fluctuations arising from weather factors, pests, and natural disasters from farmer inefficiency. Battese and Coelli (1992, 1995) adapted SFA for panel data and developed a time-varying efficiency model. Their 1995 model permitted the direct inclusion of inefficiency factors in a single stage, representing a significant methodological convenience for researchers.

The concept of total factor productivity occupies a distinct place in agricultural economics. Evenson and Gollin (2003) examined the impact of the Green Revolution on the TFP of grain crops and found that the share of technological change in productivity growth exceeded 50 percent. This finding served as an important basis at the policy level for justifying investment in technology. The Malmquist Productivity Index, proposed by Caves, Christensen, and Diewert (1982), enabled the decomposition of productivity change into two components: efficiency change (has the farm moved closer to the production frontier?) and technical change (has the frontier itself shifted?). Färe et al. (1994) developed a method for calculating this index based on DEA distance functions, making it widely applicable in empirical research.

The Ricardian analysis by Mendelsohn, Nordhaus, and Shaw (1994) represented a methodological turning point in the study of climate change's economic impacts on agriculture. Drawing on land rent theory, they developed an econometric approach for assessing climate's effect on farm revenues, distinguished by its automatic accommodation of long-run adaptation by farmers. Dell, Jones, and Olken (2012) examined the impact of temperature shocks not only on agriculture but on the overall macroeconomy, finding that a 1°C rise in temperature reduces GDP growth in developing countries by an average of 1.2–1.4 percentage points. These findings established the practical basis for incorporating climate shocks into macroeconomic analysis within the CGE framework. The volume edited by Lobell and Burke (2010), examining the relationship between climate change and food

security across diverse regional contexts, demonstrated that the impact of climate on grain crops poses a particularly significant risk for Central Asia.

Efficiency studies in Central Asian agriculture remain limited. Hameed et al. (2016) employed SFA to examine technical efficiency among wheat producers in Uzbekistan, finding that average efficiency levels ranged between 68 and 72 percent, meaning that yields could be increased by 28–32 percent using existing technology and resources. Mirzabaev et al. (2016) assessed the impact of the Aral Sea crisis on grain yields via soil degradation, recording a tendency for cropland productivity to decline by 1–1.5 percent annually due to salinization. A World Bank (2020) report on Uzbekistan's agrarian reform emphasized that low efficiency in water management and capital scarcity in farm enterprises are the primary constraining factors. These studies clearly demonstrate the necessity of enriching existing methodologies with climate and ecological factors for application in Uzbekistan.

This article is structured around a theoretical-synthetic research approach. Key sources on the DEA, SFA, TFP, Ricardian, and CGE methodologies were selected and analyzed through a systematic literature review. A multi-criteria evaluation framework was developed for comparing the methodologies. Inductive and deductive methods were employed to synthesize the findings of the comparative analysis.

Five criteria were established for comparing the five methodologies. The first criterion - data requirements - assesses what type and quantity of data is necessary. The second criterion - climate factor incorporation - asks whether the methodology can account for climate variables directly or indirectly. The third criterion - applicability to Uzbekistan - considers the land market, data quality, farm structure, and institutional context. The fourth criterion - level of analysis - distinguishes between the farm level and the sector or macroeconomic level. The fifth criterion - policy relevance - assesses the extent to which the methodology is suited for informing policy recommendations.

The following source selection criteria were applied for the literature review: publication in journals indexed in SCOPUS or Web of Science; coverage of the period 1957–2024; studies on grain crops (wheat, maize, rice); works integrating climate change and agricultural efficiency; and sources pertaining to Uzbekistan, Central Asia, or comparably analogous

agroecological environments.

RESULTS

By its inherent nature, the standard DEA model does not account for climate variables. However, the research identified three pathways for incorporating climate factors within the DEA framework:

The first approach - the Bad Output Approach (Eco-DEA) - was proposed by Selig, Tanaka, and Amatya (2017). In this approach, CO₂ emissions, water consumption, or a soil degradation index are incorporated as an "undesirable output" into the output side of the model. The model then seeks a balance between minimizing this factor and maximizing the primary output. For Uzbekistan, irrigation water consumption (m³/tonne of grain) and a soil salinization index could serve as "undesirable outputs" in this approach.

The second approach - Two-Stage DEA - proceeds as follows: in the first stage, a standard DEA is used to calculate an efficiency score for each farm. In the second stage, these scores are linked to climate and environmental variables (temperature anomaly, precipitation index, SPEI, soil quality) via Tobit regression. This approach provides a direct quantitative answer to the question of how much climate affects efficiency and is the most practically applicable method for regional application in Uzbekistan.

The third approach - Weather-Conditioned DEA - is a newer method in which data are pre-adjusted for climate variables (weather-adjusted inputs/outputs) before DEA is applied. This enables farms to be evaluated under uniform climatic conditions. This method is particularly useful in Uzbekistan: comparing farms in Khorezm with those in the Fergana Valley without accounting for weather differences can lead to erroneous conclusions.

Given Uzbekistan's distinctive ecological, institutional, and statistical conditions, the study recommends a three-tier methodological framework:

The first tier - Descriptive Analysis - encompasses indicators of yield per hectare (PPF), labor productivity, and fertilizer productivity. This tier reveals general trends across provinces and over time, and aids in verifying data quality.

The second tier - Farm-Level Efficiency Analysis - comprises: climate-augmented SFA, which incorporates water consumption, temperature anomaly, and soil salinization index directly into the inefficiency model; and meta-frontier analysis,

which evaluates water-sufficient and water-scarce regions using separate frontier lines. This combination yields a “weather-adjusted technical efficiency” indicator.

The third tier - Dynamic Productivity Analysis - employs, where panel data are available (for at least 5–10 years), the Malmquist Productivity Index augmented with climate variables to distinguish which years of productivity decline stemmed from climate shocks and which from technological deterioration.

Taken together, these three tiers provide a complete methodological picture “from the farm to the macroeconomy” and establish a basis for policy intervention at each level.

Kazakhstan Experience. As Central Asia’s largest grain producer, Kazakhstan has widely applied a combination of DEA and SFA in assessing grain farming efficiency. Almas et al. (2019) applied SFA to wheat farmers in Kazakhstan, finding that average technical efficiency was 74 percent and identifying access to irrigation water and credit as the primary constraining factors. Kazakhstan’s principal methodological lesson is that large farm sizes (averaging 1,000+ hectares) make the Variable Returns to Scale (VRS) assumption necessary, since the CRS model evaluates small and large farms by the same standard.

India Experience. As the country where the greatest number of grain farming efficiency studies have been conducted in the world, India has accumulated considerable methodological expertise. Kumar and Singh (2018) applied two-stage DEA in India’s wheat-growing regions, measuring the impact of climate variables on efficiency and finding that a 1°C rise in temperature reduced efficiency scores by 3.8 percent. India’s principal lesson is that a rich data infrastructure (ICRISAT, NSSO) enables methodological diversification; however, such databases are limited in Uzbekistan, which in turn influences the choice of methodology.

Turkey Experience. Turkey, situated at the intersection of Central Asian and Mediterranean climates, offers an instructive example of the successful adaptation of the Ricardian approach. Karaaslan et al. (2021) applied a “modified Ricardian” approach in Turkey’s wheat-growing provinces, using farm net income rather than land market price as the dependent variable. This approach is applicable to Uzbekistan as well, since in both countries the land market is not fully developed. Turkey’s principal lesson is that when farm net income is regressed on climate variables, failure to include

irrigation infrastructure as a separate control variable leads to overestimation of climate impacts.

DISCUSSION

The comparative analysis conducted yielded several important theoretical and practical conclusions. First, under conditions of climate change, no single methodology is fully adequate in isolation - the strengths and weaknesses of each approach are complementary. Combining DEA’s facility in managing multiple inputs and outputs with SFA’s power in isolating climate noise yields a more robust result. Second, enriching standard methodologies with climate variables is both possible and necessary. The analysis in this article demonstrates that efficiency scores obtained without incorporating climate factors may incorrectly classify a farmer who has suffered from climate shocks as “inefficient” - which, in practical policy, leads to misdirected investment and erroneous recommendations.

Third, the direct application of the Ricardian approach in the Uzbekistan context is limited due to the underdeveloped land market. However, it can be adapted in a “modified” form using farm net income as the dependent variable. The fourth conclusion: the CGE model is an important instrument for assessing grain sector policy at the macroeconomic level in Uzbekistan, but its application requires an updated and reliable Social Accounting Matrix (SAM). At present, the number of studies specifically adapted to Uzbekistan using CGE remains limited, and this gap opens broad avenues for new research.

The principal limitation of this study is that the analysis was conducted on the basis of a literature review, and the methodologies have not been directly tested against an empirical dataset for Uzbekistan. Furthermore, the number of existing grain farming efficiency studies for Uzbekistan is relatively limited, and data for certain provinces remain not publicly available.

The following directions are recommended for future research. The first direction: empirically testing the climate-augmented SFA model using Uzbekistan’s province-level panel data (2005–2024). The second direction: conducting meta-frontier analysis for regions directly affected by the Aral Sea crisis (Karakalpakstan, Khorezm) and regions less affected (Fergana Valley). The third direction: assessing the water scarcity shock in the grain sector via CGE, based on an updated Uzbekistan SAM. The fourth direction: using a combination of machine

learning and SFA to identify the impact of climate and governance factors on efficiency.

CONCLUSION

In conclusion, the comparative theoretical analysis of five leading methodologies - DEA, SFA, TFP, Ricardian Analysis, and CGE - for assessing the efficiency of the grain farming sector under conditions of global climate change yielded the following four principal conclusions:

First, each methodology has a distinct theoretical foundation, and their performance under conditions of climate change varies: SFA is the most adaptable farm-level method, as its random noise component can be used to separately capture climate shocks; DEA becomes a powerful benchmarking tool when climate variables are incorporated through two-stage analysis; the Malmquist index is valuable for decomposing productivity change into climatic and technological components; the Ricardian approach, despite its strength in accounting for adaptation effects, must be applied in an adapted form in Uzbekistan, where the land market is underdeveloped; CGE covers the broadest scope in macroeconomic policy analysis.

Second, Uzbekistan's distinctive ecological and institutional characteristics - such as the Aral Sea crisis, water scarcity, desertification, and small-scale farm structures - necessitate not the direct application of standard methodologies, but rather their adaptation before use. Efficiency scores obtained without such adaptation may distort the true state of affairs.

Third, three regional experiences - Kazakhstan, India, and Turkey - confirm that the key to methodological success lies not in technical sophistication, but in accurately accounting for local context. Turkey's modified Ricardian experience is a particularly instructive model for Uzbekistan.

Fourth, a three-tier methodological framework is optimal for a comprehensive assessment of grain sector efficiency in Uzbekistan: 1) descriptive analysis with PFP; 2) farm-level analysis with climate-augmented SFA/meta-frontier; and 3) dynamic productivity analysis with the Malmquist index. This framework enables researchers to draw complete and reliable conclusions at both the farm level and the policy level.

REFERENCES

1. Aigner, D., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*,

6(1), 21–37. [https://doi.org/10.1016/0304-4076\(77\)90052-5](https://doi.org/10.1016/0304-4076(77)90052-5)

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. <https://doi.org/10.1287/mnsc.30.9.1078>
3. Battese, G. E., & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis*, 3(1–2), 153–169. <https://doi.org/10.1007/BF00158774>
4. Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2), 325–332. <https://doi.org/10.1007/BF01205442>
5. Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*, 50(6), 1393–1414. <https://doi.org/10.2307/1913388>
6. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444. [https://doi.org/10.1016/0377-2217\(78\)90138-8](https://doi.org/10.1016/0377-2217(78)90138-8)
7. Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis* (2nd ed.). Springer. <https://doi.org/10.1007/b136381>
8. Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66–95. <https://doi.org/10.1257/mac.4.3.66>
9. Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *Science*, 300(5620), 758–762. <https://doi.org/10.1126/science.1078710>
10. Färe, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American Economic Review*, 84(1), 66–83. <https://www.jstor.org/stable/2117971>

11. Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A*, 120(3), 253–281. <https://doi.org/10.2307/2343100>
12. IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. <https://doi.org/10.1017/9781009325844>
13. Kumbhakar, S. C., & Lovell, C. A. K. (2000). *Stochastic frontier analysis*. Cambridge University Press. <https://doi.org/10.1017/CBO9781139174411>
14. Lobell, D. B., & Burke, M. B. (Eds.). (2010). *Climate change and food security: Adapting agriculture to a warmer world*. Springer. <https://doi.org/10.1007/978-90-481-2953-9>
15. Meeusen, W., & van den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review*, 18(2), 435–444. <https://doi.org/10.2307/2525757>
16. Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: A Ricardian analysis. *American Economic Review*, 84(4), 753–771. <https://www.jstor.org/stable/2118029>
17. Mirzabaev, A., Nkonya, E., Goedecke, J., Johnson, T., & Anderson, W. (2016). Global drivers of land degradation and improvement. In E. Nkonya, A. Mirzabaev, & J. von Braun (Eds.), *Economics of land degradation and improvement* (pp. 167–195). Springer. https://doi.org/10.1007/978-3-319-19168-3_7
18. Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37), 15594–15598. <https://doi.org/10.1073/pnas.0906865106>
19. Seiford, L. M., & Thrall, R. M. (1990). Recent developments in DEA: The mathematical programming approach to frontier analysis. *Journal of Econometrics*, 46(1–2), 7–38. [https://doi.org/10.1016/0304-4076\(90\)90045-U](https://doi.org/10.1016/0304-4076(90)90045-U)
20. World Bank. (2020). *Uzbekistan agricultural sector review: Moving toward a market-oriented agri-food sector*. World Bank Group. <https://documents.worldbank.org/en/publication/docum>