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Using the Malmquist Index in Evaluating the Productivity of Production Factors in Manufacturing Companies

L. Taghizade Tame, F. Hosseinzadeh Lotfi*
Department of Mathematics, Science and Research Branch, Islamic Azad University, Tehran, Iran.

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Abstract
Productivity, a crucial aspect of economics, refers to the efficient use of resources to maximize output. In today's world, enhancing productivity is vital for economic growth and competitiveness in global markets. Improvements in productivity lead to cost reductions, increased profitability, and better quality of products and services.
This study analyzes changes in total factor productivity by examining data from 20 manufacturing companies in the construction sector listed on the stock exchange. It aligns with the country's Fifth Development Plan and uses the Malmquist Index as the primary tool for measuring productivity. The Malmquist Index assesses technical and scale efficiency to identify productivity changes over time.
The investigation covers the period from 2010 to 2013, reflecting various economic and market conditions. The findings can help managers and policymakers pinpoint strengths and weaknesses in production processes, offering strategies to enhance productivity and efficiency in the construction industry. Additionally, these results provide valuable insights for researchers and practitioners interested in productivity and efficiency.
Given the importance of the topic, this article contributes to understanding the factors affecting productivity in manufacturing and aids in developing strategies to improve the country's economic performance.

Keywords: Data Envelopment Analysis, Malmquist Index, Total Factor Productivity.

* Corresponding author: Email: Farhad@hosseinzadeh.ir

1. Introduction

Productivity growth is considered one of the key factors in economic development and increasing the competitiveness of industries in domestic and international markets. In this context, numerous studies have examined various dimensions of productivity and its impact on economic performance. For instance, Young (1995) and Krugman (1994) highlighted the limitations of input-based growth, emphasizing that such growth is not sustainable in the long run [1,2]. On the other hand, Arora and Parminder (2008) pointed to the importance of productivity-based growth as an effective factor in improving economic performance, demonstrating that Total Factor Productivity (TFP) is regarded as the main criterion for measuring economic growth [3].

Recent studies have also shown that improvements in various areas, such as information technology, human resource management, and organizational structure, can contribute to productivity growth. For example, research conducted in recent years has examined the impact of modern technologies on productivity in manufacturing industries, reporting positive results in this regard. Additionally, in the era of globalization and liberalization, the role of government in enhancing productivity and creating a competitive environment has also gained attention.

This paper investigates the use of the Malmquist Index in assessing the productivity of production factors in manufacturing companies. Our goal is to identify the challenges and opportunities present in this field and to provide solutions for improving productivity in this sector. Given the significance of productivity in economic growth and competitiveness, such studies can contribute to a better understanding of production performance and offer practical solutions.

2- Literature Review

In recent decades, productivity assessment has emerged as a key topic in management and economics, particularly concerning manufacturing companies. One of the effective tools in this area is Data Envelopment Analysis (DEA), recognized as an efficient method for evaluating technical efficiency and productivity across various industries.

One of the important tools for assessing productivity changes over time is the Malmquist Productivity Index, which was first introduced by Malmquist (1953) and has been widely used in various research studies. Additionally, Falavigna et al. (2018) employed this index to understand judicial reforms [4]. In related research, Odeck and Schoyen (2020) utilized the Malmquist Productivity Index based on Stochastic Frontier Analysis (SFA) to evaluate productivity and convergence of container ports in Norway [5], while Khoshroo et al. (2022) proposed a dual-boundary Malmquist Productivity Index for calculating TFP in the energy sector in the presence of undesirable pollutants. Furthermore [6], Giacalone et al. (2020) used this index to assess the dynamic efficiency of the Italian judicial system [7], and Yu and Nguyen (2023) applied it to examine productivity changes in airlines in the Asia-Pacific region. Finally [8], Pourmahmoud and Bagheri (2023) used an imprecise Malmquist Productivity Index to evaluate health systems during the COVID-19 pandemic [9]. Raayatpanah and Ghasvari (2011) employed the Malmquist Productivity Index in a stochastic environment and proposed a second-degree programming problem to calculate TFP for companies. Additionally [10], Arhin et al. (2023) used a double bootstrap DEA model to evaluate the overall costs of malaria in Sub-Saharan Africa [11]. Hosseini et al. in 2023, The study assesses the progress of Iranian electricity companies (2015–2016) using DEA, extending the Malmquist index for semi-positive/negative indicators. It analyzes 16 companies with flexible benchmarks and input constraints [12].

3. The Malmquist Productivity Index and the Calculation of Total Factor Productivity

The Malmquist Productivity Index (MPI) is a widely used tool for measuring productivity changes over time. It provides a way to evaluate the efficiency of decision-making units (DMUs) by comparing their performance across different time periods. The MPI is particularly useful because it accounts for both "Technological" changes and "Technical Efficiency" changes, allowing for a comprehensive analysis of productivity dynamics.

3.1 Definition of the Malmquist Productivity Index

Consider a Decision-Making Unit ($DMUj\,; j=1,2,\ldots n$) as illustrated in Figure (1).

Assume that I represent the number of input units $x_{ij} \geq 0;\, j=1,\ldots,n, i=1,\ldots,I$ used to produce R units of the final output $y_{rj} \geq 0;\, j=1,\ldots,n, r=1,\ldots,R$.

Additionally, the production function will be examined at time periods t and t+1. The following linear programming problem is considered:

$$
\begin{aligned}
D^t(X^t, Y^t) &= Min\,\theta \qquad (1)\\
s.t: \sum_{j=1}^{n} \lambda_j x_{ij}^t &\leq \theta x_{ip}^t, \quad i=1,\ldots,I\\
\sum_{j=1}^{n} \lambda_j y_{rj}^t &\geq y_{rp}^t, \quad r=1,\ldots,R\\
\lambda_j \geq 0,\ & j=1,\ldots,n
\end{aligned}
$$

Model (1) pertains to the evaluation of DMU_p in the production function at time t, where x_{ip}^t represents the i-th input and y_{rp}^t denotes the r-th output of DMU_p at time t. The optimal solution of Model (1) yields the efficiency measure $\theta_t^{*t} = D^t(X^t, Y^t)$, which indicates the extent to which the input DMU_p can be reduced while still producing the same level of output. If Model (1) is formulated for time t+1, the technical efficiency DMU_p at time t+1 is obtained, denoted as $\theta_{t+1}^{*t+1} = D^{t+1}(X^{t+1}, Y^{t+1})$.

In a similar manner, the technical efficiency DMU_p at time t under the production function at time t+1 is defined as $\theta_{t+1}^{*t} = D^t(X^{t+1}, Y^{t+1})$, while the technical efficiency DMU_p at time t+1 under the production function at time t is also represented as $\theta_t^{*t+1} = D^{t+1}(X^t, Y^t)$. Consequently, the changes in technical efficiency from time t+1 to time t can be expressed as follows:

$$
TEC_P = \frac{D_P^{t+1}(X_p^{t+1}, y_p^{t+1})}{D_P^t(X_p^t, y_p^t)} \qquad (2)
$$

The extent of technological changes from time t to time t+1 can be expressed as a geometric combination using the following equation:

$$FS_P = \sqrt{\frac{D_P^t(X_p^{t+1}, y_p^{t+1})}{D_P^{t+1}(X_p^{t+1}, y_p^{t+1})} \times \frac{D_P^t(X_p^t, y_p^t)}{D_P^{t+1}(X_p^t, y_p^t)}} \qquad (3)$$

For the technology change index, three scenarios can occur:

1. If $FS_P > 1$, the frontier is moving positively, indicating observed progress.

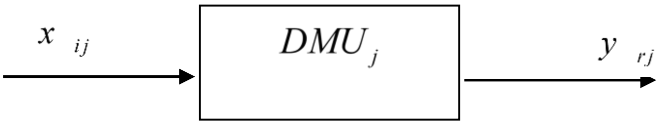

Figure 1: Decision-Making Unit j

2. If $FS_P < 1$, the frontier is moving negatively, indicating observed regression.
3. If $FS_P = 1$, it indicates that no movement is necessary, and the frontier remains unchanged.

The Malmquist Productivity Index (MPI) for each DMU_p at time t+1 compared to time t is derived from the product of efficiency changes and technological changes, expressed in relation (4):

$$MPI_P = \frac{D_P^{t+1}(X_p^{t+1}, y_p^{t+1})}{D_P^t(X_p^t, y_p^t)} \times \sqrt{\frac{D_P^t(X_p^{t+1}, y_p^{t+1})}{D_P^{t+1}(X_p^{t+1}, y_p^{t+1})} \times \frac{D_P^t(X_p^t, y_p^t)}{D_P^{t+1}(X_p^t, y_p^t)}} \qquad (4)$$

In relation (4), the following scenarios may occur:

1. If MPI>1, it can be said that there will be an increase in productivity, indicating observed progress within the organization.
2. If MPI<1, there will be a decrease in productivity, indicating observed regression within the organization.
3. If MPI=1, it indicates that there has been no change in productivity between times t and t+1.

4-Analysis of Productivity Growth Factors

In this section, 20 manufacturing companies in the construction sector that are listed on the stock exchange have been studied. The data for these companies has been collected over four consecutive years (2010 to 2013). Each company is considered as a decision-making unit according to the indicators introduced in Figure (2) below.

Using models (2), (3), and (4), the average relative values of technical efficiency at time t+1 compared to time t, the average relative values of technological efficiency at time t+1 compared to time t, as well as the average Malmquist indices related to the 20 studied companies over the 4-year period have been calculated using the GAMS software, which can be seen in Table (1).

Based on the results in Table (1), it is possible to comment on the progress and regression of the companies' productivity over the four-year study period, as shown in Table (2).

Figure 2. Input and Output Indicators of Manufacturing Companies

Table1. Result of Average Technical Efficiency Ratio, Technology Efficiency Ratio and Malmquist Index in evaluation of 20 company

DMUs	Average Technology Efficiency Ratio	Average Technology Efficiency Ratio	Malmquist Index
1	0.987	1.012	0.98
2	1.33	1.032	1.043
3	0.961	0.971	0.998
4	1.025	0.999	0.984
5	1.312	1.528	1.327
6	1.132	1.125	1.194
7	1.164	1.051	1.098
8	0.934	1.022	1.002
9	1.034	1.023	1.098
10	0.925	0.969	0.969
11	1.002	1	1.042
12	1.1	1.09	1.133
13	1	1	1.072
14	1.038	1.037	1.087
15	1.03	1.024	0.994
16	1.164	1.089	1.227
17	1.002	1.011	1.035
18	0.967	0.961	0.993
19	0.975	0.99	1.079
20	1.026	1.001	0.935

Table 2. Classification of DMUs based on the level of productivity improvement and decline using the Malmquist index.

	Malmquist Index greater than 1	Malmquist Index less than 1	Malmquist Index equal 1
DMUs	2-5-6-7-8-9-12-13-14-16-17-19	1-3-4-10-11-15-18-20	NO DMU

As shown in Table (2), based on the Malmquist index, 12 companies experienced productivity improvement and 8 companies faced productivity regression during the years 2010 to 2013, with no company maintaining constant productivity over these four years.

5-Conclusion

This study aimed to evaluate the productivity of production factors in 20 manufacturing companies during the years 2010 to 2013 using the Malmquist model. The results obtained from the analyses indicated that 12 out of the 20 companies studied experienced significant improvements in their productivity over these four years. These advancements can be attributed to various factors, including improvements in production processes, investments in modern technologies, and effective resource management.

In contrast, the other 8 companies faced a decline in productivity. This regression may be due to economic challenges, an inability to adapt to market changes, or inefficiencies in resource management.

The findings of this research not only emphasize the importance of using the Malmquist index in evaluating company performance but also highlight the necessity for continuous monitoring and ongoing improvement in production processes to maintain and enhance productivity in manufacturing industries. Furthermore, these findings can assist managers and policymakers in formulating effective strategies to improve performance and increase competitiveness in both domestic and international markets.

Ultimately, this research can serve as a scientific basis for future studies in the field of productivity assessment and efficiency analysis across various industries, underscoring the need for further research to identify the factors influencing productivity.

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