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Disaggregated productivity measurement of industrial firms using the data envelopment analysis method

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Abstract: Firms in the industrial sector in the Sultanate of Oman need to strategise by measuring and evaluating their current status regarding productivity, efficiency, and technology. Productivity measurement was conducted using data envelope analysis with data from 31 decision-making units between 2015 and 2020. It was observed that productivity performance deteriorated over this period. The average efficiency change was measured at 2.14%. Furthermore, industrial firms, on average, performed well in determining the efficiency frontier, with a measured change of 0.54%. Additionally, the calculated decomposed efficiency change score suggests that while the industrial sector is generally effective in scaling operations, it faces challenges in utilising inputs effectively. This indicates that the industrial sector did not manage its resources efficiently during the sample period.

Keywords: productivity growth; data envelopment analysis; DEA; technology; efficiency.

JEL codes: D24, C61, O14, D61.

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Biographical notes: Ahmar Qasim Qazi holds a PhD from the Wuhan University of Technology, China, with a research focus on the impact of environment and energy on economics. His work explores key areas such as productivity measurement, efficiency, and innovation determinants, with particular interest in how these factors affect industrial firms. He has published extensively in reputable international journals and has contributed to various research projects.

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1 Introduction

Productivity measurement is crucial for understanding a firm's performance and improving competitiveness in the market. Accurate and unbiased measurement of productivity is essential for policymakers, managers, and investors to make informed decisions about resource allocation, investment, and operational efficiency. The importance of productivity measurement has been highlighted by various studies. For instance, a study by Kaldor (1961) suggests that productivity growth is the main driver of economic growth in the long run. Similarly, Jorgenson et al. (1987) argue that productivity measurement is crucial for understanding the sources of economic growth and improving productivity.

The proposed method for measuring productivity has been developed based on the literature on productivity measurement. For example, a study by Färe et al. (1994) suggests that the use of data envelopment analysis (DEA) can improve the accuracy of productivity measurement by considering multiple inputs and outputs. Similarly, a study by Banker et al. (1989) suggests that the Malmquist productivity index (MPI) can be used to measure productivity changes over time. In addition to improving the accuracy of productivity measurement, the proposed method has implications for addressing bias in productivity measurement. A study by Olley and Pakes (1996) suggests that omitting certain input variables, such as materials, can lead to biased productivity measurement. Therefore, including additional input variables can provide a more accurate and unbiased measure of productivity. One such method is the DEA, which has been widely used in the literature on productivity measurement (Färe et al., 1994). DEA considers multiple inputs and outputs and provides a more accurate measure of productivity. Similarly, the MPI has been used to measure productivity changes over time (Banker et al., 1989).

The present research contributes to literature in multiple ways. Firstly, it proposes to recalculate the productivity performance by considering additional factor of production at the firm level that provides a more accurate and unbiased measure of productivity. Secondly, the study explores the implications of disaggregated productivity measurement for economic growth, which is a relatively less explored of research in the field of productivity measurement.

The MPI measured using data envelope analysis is used to measure the disaggregate productivity of firms. This method considers multiple input and output variables to provide a more accurate measure of productivity.

Other studies have investigated the role of industry-specific factors, such as market structure, regulation, and competition, in shaping firm-level productivity (Aghion et al., 2005; Baily et al., 1992; Loecker and Eeckhout, 2017). In addition, there has been growing interest in exploring the relationship between productivity and environmental sustainability (Yu and He, 2020).

To measure the MPI, this research paper will employ DEA as the primary research method. DEA is a non-parametric approach that measures the relative efficiency of firms by comparing their input-output ratios to a frontier of best practice firms (Cooper et al., 2007). DEA has several advantages over other productivity measurement techniques, including the ability to handle multiple inputs and outputs and the absence of assumptions about the functional form of the production function (Färe et al., 2010).

The objective of this research is to measure the disaggregate productivity of firms using the MPI, which is measured through data envelope analysis. The study proposes to measure productivity performance by considering an additional input variable, such as materials, to avoid the bias that arises from traditional measures that only consider output and labour inputs. Prior research in this area has typically focused on labour and capital inputs, which can lead to biased estimates of productivity if other inputs are ignored (Aigner et al., 1977; Kumbhakar and Lovell, 2000). By incorporating materials as an input, this study aims to provide a more comprehensive and accurate measurement of firm-level productivity. Secondly, the study explores the implications of disaggregated productivity measurement for economic growth, which is a relatively new area of research in the field of productivity measurement.

Since the 1970s, the Sultanate of Oman's manufacturing sector has experienced slow but consistent growth. The contribution of the manufacturing industry to the gross domestic product (GDP) here in Oman rise from 0.8% in 1970 to 9.9% in 2017, (Manufacturing for Wellbeing' The Sultanate of Oman's Manufacturing Strategy 2040, 2019). The contribution of manufacturing industry in Oman reaches around 10% that signifies the potential of the sector to contribute at the greater extend by realising and understand its requirements and keeping such needs in the priority list of upcoming strategies. Even by considering such tremendous growth, the manufacturing sector is confronting greater challenges, and it is second in number among the Gulf Cooperation Council (GCC) with respect to lowest in productivity. The growth in the manufacturing sector comes up with structural transformation. This will further bring new innovative auxiliary industries which further participate in the production processes and contribute to the economy at significant level. So, the impact of manufacturing sector contributed to the economy in the diverse way for the Sultanate of Oman, as it reduces the oil dependency. The manufacturing sector shows the linkages with respect to forward and backward. The sector has greater capacity to absorb the labour force and creating variety of opportunities that further provide the opportunities to create the skill manpower that demanded by the industry. The industrial sector has tremendous capability to bring innovation in the form of product and process and became the source of knowledge and technology spillover which produces the multiplier effect on the production.

The Oman's vision and national priorities is clearly showing to build the national innovation system where all the actors are equally responsible to play their due roles to address the new technological challenges including the manufacturing firms. The approach is justifiable as in Oman the firms in industrial sector significantly contributing to the national output. Therefore, measurement of productivity, technological and efficiency change (EC) considered to be important and timely effort to build national output more sustainable. Moreover, it is considered that the firm's competition is itself by looking at the part performances in both efficiency and technological improvement. Sultanate of Oman is low in labour productivity (Jarkas et al., 2015). By all these, to evaluate the present and past performance is very first step towards future policies. For both at the firm and macroeconomic policy level, it is required to measure the existing status of firms' performance with respect to technological adaptation, ECs and productivity.

The research paper structure is as follows: Section 2 provides a literature review on productivity measurement and its importance. Section 3 presents the methodology used in this study. Section 4 presents the results of the study, followed by a discussion of the implications of the results in Section 5. Finally, Section 6 concludes the paper and suggests future research directions.

2 Literature review

The relationship between output and inputs is the generally accepted definition of productivity among economists. Schreyer (2001) explains total factor productivity (TFP) as the size of output divided by the index of inputs used for the same. Therefore, an increase in output while maintaining the same quantity of inputs indicates that the production process's productivity has increased. Solow (1957) exploited the index number approach to calculate the neutral shift parameter given by Hicks under the production function framework. He further explains the shift parameter as the rise of ratio between output and input by keeping constant the cost level. Whereas the growth takes place which is unexplained by considering the traditional inputs (labour and capital) is called residual. Solow (1957) presented transformed input and output function that proposed significant part of the output growth to technical change known as residual. This altered model delivered the fact that was wearisome to the Griliches which led him to posed most of the measurement issues of the variables, problems associated with the model specification and the questions regarding the omitted inputs variable such as R&D investments.

However, Abramovitz (1956) named 'measure of our ignorance' to such residuals which remain unexplained, and he further divided such ignorance into to broad concepts. Abramovitz (1956) says we are more inclined to measure such ignorance because it is related to measuring the technical change and innovations of organisation that everyone interested to measure. Whereas ignorance related to error in measurement, model that is mis-specified and other related biasness arises and everyone considered as a problematic and unwanted. It is therefore scholars have put great importance to reduce the measurement errors as much as possible to accurately estimate the effects of productivity change, technological and EC and innovation.

To measure the TFP requires the accessibility and quality of input and output indices. Secondly the error free measurement estimation techniques and unbiased framework significantly improve the measurement of technical efficiency, technological change and ultimately productivity growth. There is unanimously consensus among the scholars and researchers that the TFP can be measured in variety of estimating techniques and obviously and purely differing on the goals and objectives of the research study and secondly depends on the accessibility of input and output data with good quality. Mawson et al. (2003) mentions the different approaches used by earlier researchers to measure the TFP. However, the following approaches are considered to be significant and extensively utilised, Growth accounting framework, the index number approach, the econometric approach and distance function framework.

The growth accounting framework calculates the TFP built on various beliefs. According to the methodology, the TFP can be determined by deducting the proportion of labour and capital inputs from the output. Therefore, the methodology assumes that the traditional inputs of labour and capital are considered to be observable. To calculate residual (an unexplained output), this method needs the production function approach. This approach to measure the residual has been given by the Solow (1957) and since then, the method has seen extensive use in research studies. The growth accounting approach can be found in the research studies conducted by Griliches (1963), Kendrick 1973, 1977) and North (1963).

Contrarily, the econometric approach does not call for a correlation between the production and income share elasticity's. The econometric framework requires and follows the inputs and output indices. To understand further about the approach, see Morrison (1986) and Nadiri and Prucha (2011). The econometric approach (production function) was found to be more general and promising method compared to case study, but the method was suffering from some serious problems that needed attention at that time. Griliches (1979) explored in his survey paper the assurances and challenges associated with this approach. He argued that there were some conceptual and semantic challenges which needed to be cleared up such as what we really wanted to measure. He further said that there were some substantive challenges regarding what do we measure? And some challenges were statistical or methodological.

Moreover, he explained that, in production function the output say, Y is determined by some list of inputs known as explanatory variables say, X. In such kind of functions, the conceptual problem is to determine the definition and extent of Y. The definition of Y (output) may vary depend on the goal and objectives of the research questions.

The previous studies at the firm level were unable to sufficiently control the unobserved heterogeneity, which could be appeared due to the different activities of the firms therefore the findings were not accurately obtained (Lichtenberg and Siegel, 1991). To measure the productivity growth at the firm level itself has been facing great challenges, varies by considering methodological issues to the input and output variables selections. The firm has been generally different from one another in terms of structure, size, scale of economies, management and production process. It looks unreasonable to ignore such differences and consider all units in one in order to measure the productivity growth.

Recently several studies on various sectors utilised bootstrapped MPI measurement. Assaf and Agbola (2011) explained the productivity change sources in Australian hotel by utilised the bootstrapped Malmquist index. Zhang et al. (2015) observed that the decrease in productivity performance due to decline in technological change in transportation industry of China. Gitto and Mancuso (2012) examined the productivity of airports in Italy and found productivity gap in different airports at different locations characteristics. Arjomandi et al. (2011), Christopoulos et al. (2022), Fernandes et al. (2018) and Murillo-Melchor et al. (2010) exploited similar approach to measure productivity. Moreover, the MPI with DEA by utilising the inputs and outputs measure the efficiencies of the firm by highlighting the distance from the frontier (Arya and Marbine, 2023). Additionally, green efficiency measurement has been performed for the 30 Chinese provinces by breaking the MPI into ECs, pure TCs and scale ECs (Chen et al., 2023). The approaches to measure productivity performance and the uncertainty about the quality of data utilised are major concerns among the scholars. By considering this the researchers introduced environmental fuzzy Malmquist TFP index and measured productivity for Turkey (Aldalou and Percin, 2024).

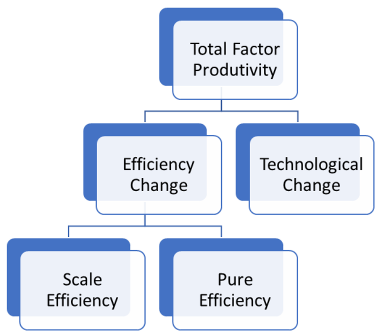
3 Research methods and techniques

The current research has exploited the method created by Fare and Grosskopf (1992) and Färe et al. (1994), which is the DEA-based on MPI. The linear programming developed by Charnes et al. (1978) forms the foundation of the DEA. They propose that decision making units (DMU) could evaluate the effectiveness of their units based on input and output. Additionally, they used an approach developed by the Farrell (1957) called frontier line method in to evaluate DMU's performance. The methodology (distance function approach) enables to capture the productivity growth changes occurred in DMUs. Furthermore, the approach also makes us capable of identifying the disaggregate sources of productivity growth observed by the DMUs that further enhance the understanding the productivity measurement.

Malmquist (1953), who built the quantity index under the consumption structure, is credited with creating the Malmquist index. Consequently, the two different concepts, the efficiency measurement initiated by the Farrell (1957) and the calculate the matrix of productivity developed by the Caves et al. (1982) are combined by the (Fare and Grosskopf, 1992) for the sole purpose to create the MPI which can be calculated completely by using the quantity of input-output data and exploiting the DEA approach. Compared to alternative methodologies, employing the MPI-DEA methodology has a number of benefits. The method is regarded as non-parametric because it makes no demands about the functional form of the inputs and outputs. It makes it possible to locate the DMU's most important frontiers. Considering that the DEA approach is not statistical in nature, the results obtained from it virtually have minimum error. Given the Malmquist index, it only requires simple computation (Färe et al., 1995). This index is related to the superlative Tornqvist and Fisher Ideal Indices based on specified requirements (Fare and Grosskopf, 1992). It only needs a few assumptions about the underlying technology and can calculate the rise of DMU production across predetermined time periods (Cooper. et al., 2004).

According to Fare and Grosskopf (1992), the productivity index based on the DEA technique is defined as the geometric mean of two indices. Therefore, the two important elements of the MPI are the EC and technical change.

Figure 1 Decomposing the productivity index (see online version for colours)



Therefore, in the context of our study to productivity measurement, it is assumed that at certain time say $t = 1 \dots \dots T$ time period, the number of firms $m = 1 \dots .. M$ has been producing the number of outputs, $y = 1 \dots .. Y$ by utilising the quantity of different inputs, such as $x = 1 \dots .. X$. Furthermore, it is assumed that each firm has an objective to achieve the maximum amount of revenue by using the certain amount of inputs; hence, output distance function approached has been exploited to measure the indices.

In our context of measuring MPI, the output-oriented framework of distance function between the two time periods is described as follows:

$$MPI_0\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^t\left(x^t, y^t\right)} \times \left[\left(\frac{D_o^t\left(x^{t+1}, y^{t+1}\right)}{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}\right)\left(\frac{D_o^t\left(x^t, y^t\right)}{D_o^{t+1}\left(x^t, y^t\right)}\right)\right]^{1/2}$$

where the left side of the equation exhibits the MPI that needs to calculate with x represents the set of inputs, y shows the outputs and t represents the time. Whereas the term $D_o^t(x^{t+1}, y^{t+1})$ describes the distance between two time periods related to technology.

In order to measure the technical efficiency, change and TC, the equation has been divided into two measurement elements. The first expression in the right side of the equation $TEC = \frac{D_o^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_o^t\left(x^t, y^t\right)}$ shows the measurement of technical efficiency change (TEC) between the two time periods showing as t current year to $t + 1$ next year. The technical efficiency score will describe the catching up effect of a firm concerning the best frontier available in all firms. On the other hand, the second term of the equation on the right side represents the shift in the frontier which arises as the firm shift the technological advancement. The following expression calculates the change in the frontier or shift in the technology between the two time periods by the firms, $FS = \left[\left(\frac{\left(D_o^t \left(x^{t+1}, y^{t+1} \right) \right.}{D_o^{t+1} \left(x^{t+1}, y^{t+1} \right)} \right) \left(\frac{\left(D_o^t \left(x^t, y^t \right) \right.}{D_o^{t+1} \left(x^t, y^t \right)} \right) \right]^{1/2}$. The score presented by such an index can be interpreted as if the FS score is greater than unity than technological advancement taking place between the periods (t, $t + 1$). If the calculated FS score is below the unity than technology improvement is not obtained by the firms between the periods. And last, but not the least, if the FS score is equal to the unity than there is no improvement or deterioration related to technology by the firms between the two time periods (Fare and Grosskopf, 1992; Färe et al., 1994).

While the multiplication of the two indices, TEC and frontier shift (FS) produces the MPI. Similarly, the MPI score can be interpreted as if the score from between the period t to $t + 1$ is greater than unity that refers the increased in productivity performance, if the MPI score is less than unity will be interpreted as deteriorated productivity performance and at last if the score is equal to unity refers to no change in the productivity performance.

Furthermore, the TEC is divided into two more measurement scales namely pure TEC and scale EC. The firm is scale efficient when it starts to perform at the optimal in consideration of the size of the firm. It is therefore, if there is any change in the size leads to yield less efficient. The model of scale efficient can be described in increasing returns to scale and decreasing returns to scale. The current research has exploited the model with the variable returns to scale specification in order to capture the changes in the pure efficiency of the firms.

To measure the MPI with the components of TEC and FS, The research has utilised the DEA method. It is a non-parametric approach used for creating benchmarking of the firm's performance. Therefore, the research must tackle four different linear programming problems in this context; thus, the research assumed the constant returns to scale (CSR) for the same. Moreover, to calculate two more decomposed indices of TEC, named pure efficiency change (PEC) and scale change (SC), two additional linear programming equations must be created and solved (Färe et al., 1994).

In the context of our study, following four linear programming is set up,

$$\begin{aligned} &\left[d_0^t \left(y_t, x_t \right) \right]^{-1} = \max_{\varphi,\omega} \varphi \\ &\textit{subject to} \quad -\varphi y_{it} + Y_t \omega \geq 0, \\ &\quad x_{it} - X_t \omega \geq 0, \\ &\quad \omega \geq 0, \end{aligned}$$

$$\begin{aligned} &\left[d_0^s \left(y_s, x_s \right) \right]^{-1} = \max_{\varphi,\omega} \omega \\ &\textit{subject to} \quad -\varphi y_{is} + Y_s \omega \geq 0, \\ &\quad x_{is} - X_s \omega \geq 0, \\ &\quad \omega \geq 0, \end{aligned}$$

$$\left[d_0^t\left(y_s, x_s\right)\right]^{-1} = \max_{\varphi,\omega} \varphi$$
$$\textit{subject to} \quad -\varphi y_{is} + Y_t\omega \geq 0,$$
$$x_{is} - X_t\omega \geq 0,$$
$$\omega \geq 0,$$

$$\left[d_0^s\left(y_t, x_t\right)\right]^{-1} = \max_{\varphi,\omega} \omega$$
$$\textit{subject to} \quad -\varphi y_{it} + Y_s\omega \geq 0,$$
$$x_{it} - X_s\omega \geq 0,$$
$$\omega \geq 0,$$

where ω represents the weights and φ shows the form of scalar. The obtained score of φ will be greater than or equal to the one, hence, the by the subtraction of the value of φ from the one exhibit the fraction of rise in the quantity of output which is the outcome obtained by exploiting the equal number of inputs. On the other hand, the terms X and Y showing the input and output indices of the total firms chosen.

4 Data and variables

The present study utilised the data of 31 industrial firms listed in the Muscat Security Exchange, sultanate of Oman for the period of six years from 2015–2020. The data has been published by the firms in their annual financial reports. Each firm is the decision-making units (DMUs) and the list of the included firms is presented in Appendix A of this research report. The measurement of the MPI is subject to the careful selection of the inputs and outputs. By using the earlier research and availability of the published data, the present study has finalised one output and three inputs for the measurement of the index. The selection of the variables does matter and significantly affect the measurement, therefore, to avoid the biasness the research included materials input as an effective combination along with labour and capital inputs (Morita and Avkiran, 2009). Table 1 shows the input and output variables used to measure the MPI. All the values obtained are in Omani Rial. The production function of any firm shows the relationship between input and output. In present research the revenue of the firm received after the selling of the goods and services shows how effectively a firm converts its inputs into products, ultimately representing the performance of the firm. In the current research, wage bill represents the amount of the money given to the labour force for in the firm for providing services proxy the labour input in the production function. The wage bill is adjusted with inflation to obtain the true value of the wage bill. There is a direct relationship between labour input and output in the production function as more labour would lead to higher output. The second traditional input is named capital, which is proxied by the firm's total assets. The amount of money put into use such as machinery, building and equipment which play an important role in the production process. The firm's total assets are adjusted with inflation to get the real value of the assets of the firm. The higher level of capital input leads to a greater output level as capital enhances the production capabilities of the firm. The cost incurred by the firm in purchasing the raw materials used in the production process. The amount and quality of the materials utilised by the firm directly impacts the quantity of the output. In other words, the use of more quality materials leads to higher production and consequently greater levels of revenue.

Table 1 Input and output variables

Variables	*Description*	*Reference(s)*
Output	Revenue: the revenue shows the performance of the firm by producing and selling goods and services.	Le et al. (2018)
Input – labour	Real wage bill: labour input is measured through the wage bill, the cost of hiring the labour services.	Le et al. (2018)
Input – capital	Real total assets: the capital input represents the total assets in the form of machinery, equipment and buildings utilised for production purposes.	Le et al. (2018), Wu et al. (2007), and Mohan (2020)
Input – materials	Cost of materials consumed: materials represent the cost incurred to obtain the raw materials used in the production process.	Le et al. (2018)

5 Results and discussion

Firstly, the results are presented and discussed by firm-wise in the form of averages of the obtained score over the study period. The results are obtained by following the model of output oriented as discussed in the methods and techniques section. Furthermore, the model is assumed to have CSR to get the productivity, technical efficiency and FS scores.

Table 2 exhibits the average productivity measurement score of each firm over the period of 2015 to 2020, obtained by the CSR model specification. The table shows the measured score of Malmquist productivity change score and decomposed indices namely FS or technology change (TC) and EC over the study period. It is further to confirm that the score of productivity can be interpreted as if the calculated score is greater than unity than it said to be productivity performance improved, the less than unity score refers to be deteriorated productivity performance and if the obtained score is equal to one suggests not change in the productivity performance. The technical change and EC indices can also be interpreted in a similar fashion.

Moreover, the measured score shows the performances of each firm that is comparing with the best practice and the best practice is the frontier of whole industrial sector where all the firms operating in Sultanate of Oman. Hence, the firms try to catch-up the frontier is showing EC whereas shift in the frontier is technological change experienced by the firms.

Table 2 shows the overall average score of the productivity performance of industrial sector over the study period from 2015–2020 is slightly below the unity that suggests the productivity performance deteriorated over this period. Whereas the mean ECs experienced by the industrial over the study period is improved and around 2.14%. That suggests the firms on average in the industrial sector are good at catching-up the frontier and on the other hand, the mean technical changes over the study period are also improved and around 0.54%. This means, on average, the firms in the industrial sector are also better in determining new frontier and adopting technological change. The average results do not give us an idea that which firm actually shifts the frontier.

Table 2 Average changes in TFP, efficiency and technical from 2015–2020 at the firm level

Decision making units	*TFP*	*EC*	*TEC*
1	0.98098	1.07048	0.94138
2	1.04796	1.13024	1.0862
3	1.41488	1.30282	1.01264
4	1.03258	1	1.03258
5	0.9959	1.07208	1.02938
6	0.97666	1.05026	0.94576
7	1.04492	1.02032	0.99548
8	1.02828	1.00742	0.99578
9	1.0279	1.0053	1.0244
10	0.98558	0.94914	0.9997
11	0.87342	0.87676	1.01166
12	0.99078	1.02674	0.97162
13	0.93812	0.93054	1.01826
14	0.93814	0.96524	0.97248
15	1.28782	1.25788	1.00588
16	1.07432	1.04732	1.03322
17	0.98522	0.98858	1.01618
18	0.96838	1.0338	0.96564
19	0.87924	0.86056	1.04766
20	0.9879	0.98598	1.0172
21	0.91992	0.93906	1.00872
22	0.92484	0.95348	0.96986
23	0.97074	1	0.97056
24	0.98592	0.99096	1.02312
25	0.9958	1.00284	0.99102
26	0.8148	0.79244	1.01754
27	0.98626	1.03178	1.00972
28	0.97924	1.09668	1.00582
29	1.01216	1.12716	1.0373
30	0.9808	1.17838	1.01942
31	0.9593	0.97152	0.99164
Average	*0.99963742*	*1.0214761*	*1.00541355*

Source: Authors' calculation

The firm wise results exhibit that the highest productivity improvement during the study period experienced by the number 3rd DMU with average of 41.4% growth. The greater productivity improvement for this firm is mostly because of EC contribution that average growth for the sample period is around 30.2%. This suggests the company has been doing good in catching up the best practices. Following the number 3rd DMU, the DMU number 15 is leading in the productivity performance with an average growth over the sample period around 28.7% which mostly supported by the efficiency with an average change is around 25.7% during the period of the study.

Furthermore, it is observed in the measured score that the firms in the industrial sector are performing well in catching-up the frontier means bring EC compared to the shift in the frontier (innovation). The score shows the average EC of all the firms over the sample period is around 2.1% compared to the technical change which is around 0.54% in the same period. That suggests the EC mostly determines the productivity performances in these firms instead of technical change. This conclusion can further lead to identify the factors associated with productivity performances of the firms and improve the technical performances of the firms.

On average the productivity performance deteriorated over the sample period by 0.03%. At the firm individual firm level, the DMU number 11 productivity performances is significantly deteriorated around 12.6% over the sample period of the study, the major reason is deteriorated efficiency performance which is almost the same percentage of productivity deterioration. Similarly, corresponding to the DMU number 26 is also experienced deteriorated productivity performance over the study period around 18.5% with the same deteriorated performance in the efficiency. Whereas the firms corresponding DMU number 1 and DMU number 6 experienced deteriorated technical change performance over the study period for these companies. Both firms around 5.8% on average deteriorated and failed to bring innovation or shift the frontier in sample period, this further negatively affected the productivity performances for these firms which can clearly observed from their measured score.

Table 3 Average TFP, efficiency and technical change year-wise

Year	*TFP*	*EC*	*TEC*
2015–2016	0.935013	1.195106	0.813442
2016–2017	1.067845	0.917323	1.190674
2017–2018	1.052445	1.01851	1.037548
2018–2019	1.040087	0.94459	1.109171
2019–2020	0.902797	1.031852	0.876232

Source: Authors' calculation

Table 3 shows the yearly measured score of all firms related to productivity performance, TECs and technological change in the manufacturing industry particularly over the study period of 2015 to 2020.

Table 3 shows the TFP performance of the industrial sector including the sample of 31 firms from the year 2015 to 2022. The calculated score and the figure clearly suggest the productivity performance of the industrial sector in Oman has been deteriorating consecutively from the year 2016 to 2020. Firstly, the productivity performance is slowly declining and after the year of 2019 a sharp declined in productivity performance is observed. This sharp deterioration one can easily refer to the Coronavirus (COVID-19) where at the start of the pandemic, the Sultanate of Oman like following the world and international precautionary standards, the government strict the movement and imposed lockdown which significantly and negatively affected the economy in general and firms in particular. These claims and findings are consistent with the other studies for different sectors for Sultanate of Oman, such as for the findings of construction industry in Oman suggests the similar negative impact of the COVID-19 in this industry (Al Amri, 2021).

The variations in the productivity performance of the industrial firms in Sultanate of Oman could be referred to economic reasons. The Oman's strategic direction to shift economy from oil sector to non-oil sector resulted to push innovation and competitiveness in the industrial sector which creates productivity variations. Another, economic reason of the productivity variation is lack of foreign direct investment in manufacturing sector due to the ownership restrictions and consequently it creates barriers to knowledge and technology spillover which further affecting productivity performance. Furthermore, the Oman has been confronting the mismatch with respect to skills available among people and skills required by the industry, and particularly this mismatch is more in the manufacturing sector which leads to inconsistent productivity performances (IMF, 2018).

The productivity performance is gradually falling, and by the year 2019, a dramatic decline is seen.

Furthermore, the by considering constant regression assumption the fitted trend line has been drawn on the productivity change over the sample period. The trend line shows the productivity deterioration for the industrial sector in Oman. The trend line exhibits the productivity performance is above the unity and considered to be positive productivity growth experienced by the industrial sector but over the years the performance trend is declining till the year 2020. However, the deterioration in productivity performance is slow in pace as suggest the trend line. Although this trend line gives us a general notion of the beneficial impact of time on productivity growth, it cannot determine with certainty its statistical significance. For a similar purpose, the regression analysis could confirm the significance level, however, that is beyond the scope of our study.

In the sample time period, it is hard to determine unambiguously the factor behind the productivity deterioration of the industrial sector. As the EC and technical change both remain volatile during the study period. Table 3 shows the EC year after year is remain unstable as progressive in one year and deteriorating in another year. The consistency of efficiency has not been observed in the industrial sector of Oman. However, the technical change score suggests some consistency for the three years from 2016 to 2019 where the technical change performance is positive as the score is more than unity.

The measurement of technical efficiency can be divided into further two elements as discussed in detail at the method and technique section of this report. The pure technical efficiency and scale efficiency are the two decomposed indices of the technical efficiency. If the firm is operated at the optimal level, then it is considered to be scale efficiency. The results for these two indices have be obtained by utilising two model settings namely, increasing returns to scale and decreasing returns to scale. Furthermore, the context of variable returns to scale is another model setting to observe the pure technical efficiency of the firm. Table 4 shows the average score of pure and scale efficiencies of the firms in industrial sector over the period of 2015 to 2020.

The average score of technical efficiency in Table 4 shows that the industrial efficiency is progressive over the study period and that is due to the scale efficiencies. However, pure technical inefficiency is experienced by the industry in the same study period. Therefore, it is suggested that under the variables returns to scale the industry has been struggling to efficiently employ its inputs. This type of problem is generally related to the firm's managerial competencies. Whereas the scale efficiency is above the unity suggests that the overall industrial sector has been considerably better in employing the resources optimally with respect to the size of the structure.

Table 4 Average changes in efficiency, pure efficiency and scale efficiency from 2015–2020 at the firm level

DMUs	*EC*	*PTEC*	*SEC*
1	1.070	0.970	1.103
2	1.130	0.981	1.152
3	1.303	1.025	1.271
4	1.000	0.960	1.042
5	1.072	0.983	1.091
6	1.050	1.012	1.038
7	1.020	1.027	0.993
8	1.007	0.949	1.062
9	1.005	1.006	1.000
10	0.949	1.018	0.932
11	0.877	0.945	0.928
12	1.027	0.981	1.047
13	0.931	0.986	0.944
14	0.965	0.973	0.992
15	1.258	0.996	1.263
16	1.047	0.958	1.094
17	0.989	0.949	1.042
18	1.034	0.966	1.071
19	0.861	0.945	0.911
20	0.986	0.985	1.001
21	0.939	0.983	0.956
22	0.953	0.970	0.983
23	1.000	0.981	1.020
24	0.991	1.025	0.967
25	1.003	0.960	1.045
26	0.792	0.983	0.806
27	1.032	1.012	1.020
28	1.097	1.027	1.068
29	1.127	0.949	1.188
30	1.178	1.006	1.172
31	0.972	1.018	0.954
Average	*1.021*	*0.985*	*1.037*

Source: Authors' calculation

At the individual firm level, the firm Al Fajar Al Alamia is considered to be most efficient firm to achieve the frontier due both pure and scale efficiency. That suggests the firm has been exploiting the inputs efficiently as well as utilising the production plant effectively and optimally. On the other hand, the firm Sweets of Oman efficiency performance is deteriorated due to both pure and scale efficiencies. So, the firm needs to find out the best practices in utilising the inputs efficiently and also needs to adopt the procedure to achieve the optimal utilisation of the production plant. The individual firm level and year-wise scores of productivities, efficiency and technical changes can be found in Appendix B for reference purpose.

6 Conclusions and recommendations

Firstly, the present research has exploited the non-parametric approach to measure TFP of the firms registered in the Muscat Security Exchange under the industrial sector of Sultanate of Oman by using the MPI. This approach has an added advantage to measure the decomposed indices components namely, TECs index and technical change index. This enables us to explore the productivity growth sources of each firm and average industrial in the form of efficiency growth and technical growth. To measure MPI, DEA method is utilised, a non-parametric approach. This approach uses the best practices technique and draws the frontier of benchmarking by adopting the linear programming technique for the indices. The chances of calculation errors remain limited under the DEA method due to its non-statistical characteristics. Therefore, the un-biased and efficient measurement of productivity index critically depends on the quality of production inputs and outputs. By such consideration, the present study has placed due care in selection of the inputs and outputs and its quality and take on into the measurement errors related to variables. It is, therefore, the research has included the cost of materials as an additional input beside the traditional inputs of labour and capital to avoid the biasness arises otherwise. Most of the earlier research ignored this variable and produces biased results.

The calculated scores of MPI shows the overall the industrial sector's productivity performance for the study period of 2015–2020 is somewhat below one, suggesting that this sector's productivity performance declined during this time. While the average ECs for the industrial sector over the study period was better and amounted to about 2.14%. In addition, the mean technological changes over the study period are also better and are around 0.54%, which suggests that enterprises in the industrial sector are often thought to be good at catching-up to the frontier. This indicates that, generally speaking, industrial sector businesses are stronger at identifying new frontiers and embracing technological progress. Additionally, it is seen in the measured score that the industrial sector's businesses are doing well in terms of catching up to the frontier by bringing about EC in comparison to the frontier's shift (innovation). According to the score, all of the enterprises' average EC throughout the sample period was about 2.1%, but the technical change during the same period was about 0.54%. This shows that ECs rather than technological changes are what largely affect productivity achievements in these organisations. This conclusion might help to pinpoint the variables that affect a company's productivity performance and enhance the technological capabilities of the company.

It is found on the analysis of year-wise averages of the MPI of industrial sector from the year 2015 to 2020. The estimated score and the data unmistakably show that Oman's industrial sector's productivity performance has been declining steadily between 2016 and 2020. One can easily compare this sudden decline to the Coronavirus (COVID-19), in which the Sultanate of Oman, in accordance with global and international precautionary standards, restricted movement and imposed a lockdown that had a profoundly negative impact on the economy in general and businesses in particular.

Secondly, the variations are more related to macroeconomic reasons of transition from oil based to non-oil economy, labour mismatch and lack of foreign direct investment.

The study discovers that the industry performs well overall at the size of operations but has significant challenges due to the overuse of inputs. This leads us to conclude that the industry is not effectively managing its resources overall during the sample period. By creating strategies geared at skill development programs to improve the professional performance of the labour force, the industry should have made more investments in the development of human capital. Human capital has typically been found to have the capacity to develop more skilled managers and to aid in the adoption of cutting-edge technology. The productivity of each worker would invariably rise with the combination of competent labour and cutting-edge technology. Therefore, a significant degree of human capital should be invested in the technologically advanced industry available to boost technical effectiveness and hence productivity. Otherwise, the unskilled labour force would be unable to utilise the technology effectively, leading to persistent inefficiency.

At the firm level analysis, it is observed that the deteriorated productivity performances of Gulf International Chemicals and Sweets of Oman corresponding the DMU number 11 and 26 are due to the deteriorating performance of efficiency. Furthermore, the deteriorated performance in efficiency in these firms is due to both poor performance in both pure efficiency and scale efficiency. It is recommended for these firms to consider revisiting utilisation of process optimisation techniques, training of the employees, allocate the resources efficiently, realise the market expansion, consider for the vertical integration and review the cost structure of fixed and variable costs. Moreover, the firms Construction Materials Industry and Packaging Co. Ltd corresponding to DMU number 1 and 6, challenged with technical improvement as a result productivity growth is affected. The recommendations for these firms invest and build in house R&D department which help to create new goods and services as well as help to understand the adopted technology. Moreover, converting the different aspects of the business operations to digitalisation would help to bring technical improvement and hence productivity improvement takes place.

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References

Abramovitz, M. (1956) *Resource and Output Trends in the United States since 1870* in Abramovitz, M. (Ed.), National Bureau of Economics.

Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2005) 'Competition and innovation: an inverted-U relationship', *Q.J. Econ.*, Vol. 120, pp.701–728, https://doi.org/10.1093/qje/120.2.701.

Aigner, D., Lovell, C.A.K. and Schmidt, P. (1977) 'Formulation and estimation of stochastic frontier production function models', *J. Econom.*, Vol. 6, pp.21–37, https://doi.org/10.1016/0304-4076(77)90052-5.

Al Amri, T. (2021) ‘The economic impact of COVID-19 on construction industry: Oman’s case’, *European Journal of Business and Management Research*, Vol. 6, https://doi.org/10.24018/ejbmr.2021.6.2.806.

Aldalou, E. and Percin, S. (2024) ‘An innovative approach to evaluating sustainable development performance: the case of the Turkey’, *International Journal of Procurement Management*, Vol. 13, No. 1, pp.1–23.

Arjomandi, A., Valadkhani, A. and Charles, H. (2011) ‘Analysing productivity changes using the bootstrapped Malmquist approach: the case of the Iranian banking industry’, *Australasian Accounting, Business and Finance Journal*, Vol. 5, No. 3, pp.35–56.

Arya, A. and Marbini, A.H. (2023) ‘A new efficiency evaluation approach with rough data: an application to Indian fertilizer’, *Journal of Industrial and Management Optimization*, Vol. 19, No. 7, pp.5183–5208.

Assaf, A.G. and Agbola, F.W. (2011) ‘Total productivity in the Australian hotel industry: estimating and bootstrapping Malmquist indices’, *Tourism Analysis*, Vol. 16, https://doi.org/10.3727/108354211X13110944387121.

Baily, M.N., Hulten, C. and Campbell, D. (1992) *Productivity Dynamics in Manufacturing Plants*, Brookings Pap Econ Act 23, pp.187–267.

Banker, R., Chames, A., Cooper, W.W., Swarts, J. and Thomas, D.A. (1989) ‘An introduction to data envelopment analysis with some of its models and their uses’, *Research in Governmental and Nonprofit Accounting*, Vol. 5, pp.125–163, ISBN: 0-89232-975-0.

Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982) ‘The economic theory of index numbers and the measurement of input, output, and productivity’, *Econometrica*, Vol. 50, https://doi.org/10.2307/1913388.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) ‘Measuring the efficiency of decision making units’, *Eur. J. Oper. Res.*, Vol. 2, pp.429–444, https://doi.org/10.1016/0377-2217(78)90138-8.

Chen, X. et al. (2023) ‘A new Malmquist-type green total factor productivity measure: an application to Chine’, *Energy Economics*, Vol. 117.

Christopoulos, A., Dokas, I., Katsimardou, S. and Spyromitros, E. (2022) ‘The Malmquist productivity measure for UK-listed firms in the aftermath of the global financial crisis’, *Operational Research*, Vol. 22, https://doi.org/10.1007/s12351-020-00595-1.

Cooper, W.W., Seiford, L.M. and Tone, K. (2007) *Data Envelopment Analysis*, Springer US, New York, NY, https://doi.org/10.1007/978-0-387-45283-8.

Cooper, W.W., Seiford, L.M. and Zhu, J. (2004) ‘Data envelopment analysis’, in *Handbook on Data Envelopment Analysis*, Springer, Springer, New York, NY, Hardcover ISBN978-1-4419-6150-1.

Fare, R. and Grosskopf, S. (1992) ‘Malmquist productivity indexes and Fisher ideal indexes’, *The Economic Journal*, Vol. 102, https://doi.org/10.2307/2234861.

Färe, R., Grosskopf, S. and Margaritis, D. (2010) ‘Time substitution with application to data envelopment analysis’, *Eur. J. Oper. Res.*, Vol. 206, pp.686–690, https://doi.org/10.1016/j.ejor.2010.03.021.

Färe, R., Grosskopf, S. and Roos, P. (1995) ‘Productivity and quality changes in Swedish pharmacies’, *Int. J. Prod. Econ.*, Vol. 39, https://doi.org/10.1016/0925-5273(94)00063-G.

Färe, R., Grosskopf, S., Norris, M. and Zhang, Z. (1994) ‘Productivity growth, technical progress, and efficiency change in industrialized countries’, *Am. Econ. Rev.*, Vol. 84, No. 1, pp.66–83.

Farrell, M.J. (1957) ‘The measurement of productive efficiency’, *J.R Stat Soc Ser A*, Vol. 120, p.253, https://doi.org/10.2307/2343100.

Fernandes, F.D.S., Stasinakis, C. and Bardarova, V. (2018) ‘Two-stage DEA-truncated regression: application in banking efficiency and financial development’, *Expert Syst. Appl.*, Vol. 96, https://doi.org/10.1016/j.eswa.2017.12.010.

Gitto, S., and Mancuso, P. (2012) ‘Bootstrapping the Malmquist indexes for Italian airports’, *Int. J. Prod. Econ.*, Vol. 135, https://doi.org/10.1016/j.ijpe.2011.08.014.

Griliches Z. (1979) 'Issues in assessing the contribution of research and development to productivity growth', *The Bell Journal of Economics*, Vol. 10, No. 1, pp.92–116.

Griliches, Z. (1963) 'The sources of measured productivity growth: United States agriculture, 1940-60', *Journal of Political Economy*, Vol. 71, No. 4, pp.331–346.

IMF (2018) *Trade and Foreign Investment – Keys to Diversification and Growth in the GCC*, Policy Papers, International Monetary Fund.

Jarkas, A.M., Al Balushi, R.A. and Raveendranath, P.K. (2015) 'Determinants of construction labour productivity in Oman', *International Journal of Construction Management*, Vol. 15, pp.332–344, https://doi.org/10.1080/15623599.2015.1094849.

Jorgenson, D.W., Gollop, F.M. and Fraumeni, B.M. (1987) *Productivity and U.S. Economic Growth*, Harvard University Press, Harvard University, USA.

Kaldor, N. (1961) *Capital Accumulation and Economic Growth, in: The Theory of Capital*. Palgrave Macmillan UK, London, pp.177–222, https://doi.org/10.1007/978-1-349-08452-4_10.

Kendrick, J.W. (1973) 'Productivity trends', *Business Economics*, Vol. 8, No. 1, pp.56–61.

Kendrick, J.W. (1977) *Understanding Productivity: An Introduction to the Dynamics of Productivity Change*, The Johns Hopkins University Press, Baltimore, USA.

Kumbhakar, S.C. and Lovell, C.A.K. (2000) *Stochastic Frontier Analysis*, Cambridge University Press, New York, https://doi.org/10.1017/CBO9781139174411.

Le, V., Vu, X-B. and Nghiem, S. (2018) 'Technical efficiency of small and medium manufacturing firms in Vietnam: a stochastic meta-frontier analysis', *Economic Analysis and Policy*, Vol. 59, pp.84–91.

Lichtenberg, F.R. and Siegel, D. (1991) 'The impact of R&D investment on productivity-new evidence using linked R&D-LRD data', *Econ. Inq.*, Vol. 29, pp.203–229, https://doi.org/10.1111/j.1465-7295.1991.tb01267.x.

Loecker, J.D. and Eeckhout, J. (2017) *The Rise of Market Power and the Macroeconomics Implications*, Working Paper 23687, National Bureau of Economic Research, Cambridge, DOI: 10.3386/w23687.

Malmquist, S. (1953) 'Index numbers and indifference surfaces', *Trabajos de Estadistica*, Vol. 4, https://doi.org/10.1007/BF03006863.

Mawson, P., Carlaw, K.I. and McLellan, N. (2003) *Productivity Measurement: Alternative Approaches and Estimates*, New Zealand Treasury, Working Paper 03/12, New Zealand.

Ministry of Commerce and Industry, Sultanate of Oman (2019) *Manufacturing for Wellbeing' The Sultanate of Oman's Manufacturing Strategy 2040*, United Nations Industrial Development Organization, 1st ed., Muscat.

Mohan, P. (2020) 'Human capital and technical efficiency: a stochastic frontier analysis of Caribbean firms', *Journal of Education and Work*, Vol. 33, No. 2, pp.143–153, DOI: 10.1080/13639080.2020.1747050.

Morita, H. and Avkiran, N.K. (2009) 'Selecting inputs and outputs in data envelopment analysis by designing statistical experiments', *Journal of the Operations Research, Society of Japan*, Vol. 52, No. 2, pp.163–173.

Morrison, C.J. (1986) 'Productivity measurement with non-static expectations and varying capacity utilization', *J. Econom*., Vol. 33, https://doi.org/10.1016/0304-4076(86)90027-8.

Murillo-Melchor, C., Pastor, J.M. and Tortosa-Ausina, E. (2010) 'A bootstrap approach to analyse productivity growth in European banking', *Journal of the Operational Research Society*, Vol. 61, https://doi.org/10.1057/jors.2009.114.

Nadiri, M.I. and Prucha, I. (2001) 'Dynamic factor demand models and productivity analysis', in Hulten, C.R., Harper, M.J. and Dea, E.R. (Eds.): *New Developments in Productivity Analysis*, pp.103–172, NBER, University of Chicago Press, USA.

North, D.C. (1963) 'The sources of economic growth in the United States and the alternatives before us by Edward F. Denison, Committee for Economic Development, New York: 1962, p.308. $4.00 (paperback)', *J. Econ. Hist.*, Vol. 23, https://doi.org/10.1017/S0022050700104206.

Olley, G.S. and Pakes, A. (1996) 'The dynamics of productivity in the telecommunications equipment industry', *Econometrica*, Vol. 64, p.1263, https://doi.org/10.2307/2171831.

Schreyer, P. (2001) 'The OECD productivity manual: a guide to the measurement of industry-level and aggregate productivity', *International Productivity Monitor, Centre for the Study of Living Standards*, Vol. 2, pp.37–51.

Solow, R.M. (1957) 'Technical change and the aggregate production function', *Rev Econ Stat.*, Vol. 39, https://doi.org/10.2307/1926047.

Wu, Z.B., Yeung, G., Mok, V. and Han, Z. (2007) 'Firm-specific knowledge and technical efficiency of watch and clock manufacturing firms in China', *International Journal of Production Economics*, Vol. 107, No. 2, pp.317–332.

Yu, D. and He, X. (2020) 'A bibliometric study for DEA applied to energy efficiency: trends and future challenges', *Appl. Energy*, Vol. 268, p.115048, https://doi.org/10.1016/j.apenergy.2020.115048.

Zhang, N., Zhou, P. and Kung, C-C. (2015) 'Total-factor carbon emission performance of the Chinese transportation industry: a bootstrapped non-radial Malmquist index analysis. *Renewable and Sustainable Energy Reviews*, Vol. 41, https://doi.org/10.1016/j.rser.2014.08.076.

Appendix A

Table A1 Firms and given numbers in industrial sector

No.	*DMUs*
1	Construction Materials Industries SAOG
2	Al Anwar Ceramic Tiles Company SAOG
3	FAJAR ALAMIA (AFAI)
4	NATIONAL BISCUIT (NBII)
5	OMAN CHROMITE (OCCI)
6	PACKAGING CO. LTD (PCLI)
7	COMPUTER ST.IND (CSII)
8	DHOFAR BEVERAGES (DBCI)
9	JAZEERA STEEL PROD (ATMI)
10	DHOFAR CATTLE (DCFI)
11	Gulf International Chemicals SAOG
12	Voltamp Energy SAOG
13	A'SAFFA FOODS SAOG
14	SALALAH MILLS (SFMI)
15	MAJAN GLASS (MGCI)
16	National Aluminum Products Company SAOG
17	Muscat Thread MILL (MTMI)
18	GULF MUSHROOM PRODUCTS (GMPI)
19	Gulf Stone Company SAOG

Source: Muscat Security Exchange

Table A1 Firms and given numbers in industrial sector (continued

No.	*DMUs*
20	The National Detergent Company SAOG
21	National Mineral Water Company SAOG
22	Oman Cables Industry (SAOG)
23	Oman Flour Mills Company (SAOG)
24	OMAN PACKAGING Company (OPCI)
25	Oman Refreshment Company (SAOG)
26	Sweets of Oman (SAOG)
27	Al Maha Ceramics (SAOG)
28	Oman Chlorine (SAOG)
29	Oman Cement Company (SAOG)
30	Raysut Cement Company (SAOG)
31	Dhofar Fisheries and Food Industries

Source: Muscat Security Exchange

Appendix B

Table B1 Firm-wise and year-wise productivity, efficiency and technical change over the study period

DMUs	*Year*	*TFP*	*EC*	*TEC*
Construction Materials Industries SAOG	2015~2016	0.836	1.312	0.637
	2016~2017	0.981	0.834	1.176
	2017~2018	1.043	1.076	0.969
	2018~2019	1.085	1.037	1.046
	2019~2020	0.961	1.094	0.879
Al Anwar Ceramic Tiles Company SAOG	2015~2016	1.197	1.782	0.672
	2016~2017	0.989	0.482	2.050
	2017~2018	0.891	1.063	0.839
	2018~2019	1.097	1.086	1.011
	2019~2020	1.065	1.239	0.860
FAJAR ALAMIA (AFAI)	2015~2016	0.974	1.563	0.623
	2016~2017	3.303	2.042	1.617
	2017~2018	1.345	1.332	1.009
	2018~2019	0.931	0.951	0.978
	2019~2020	0.522	0.626	0.835
NATIONAL BISCUIT (NBII)	2015~2016	0.807	1.000	0.807
	2016~2017	1.512	1.000	1.512
	2017~2018	0.919	1.000	0.919

Source: Authors' calculation

Table B1 Firm-wise and year-wise productivity, efficiency and technical change over the study period (continued)

DMUs	*Year*	*TFP*	*EC*	*TEC*
NATIONAL BISCUIT (NBII)	2018~2019	1.109	1.000	1.109
	2019~2020	0.817	1.000	0.817
OMAN CHROMITE (OCCI)	2015~2016	1.374	1.906	0.721
	2016~2017	0.767	0.473	1.623
	2017~2018	0.867	1.090	0.795
	2018~2019	1.362	1.105	1.233
	2019~2020	0.609	0.787	0.775
PACKAGING CO. LTD (PCLI)	2015~2016	1.124	1.417	0.793
	2016~2017	0.953	0.937	1.016
	2017~2018	0.900	0.849	1.061
	2018~2019	1.074	1.138	0.944
	2019~2020	0.833	0.910	0.916
COMPUTER ST.IND (CSII)	2015~2016	0.926	0.987	0.938
	2016~2017	2.029	1.683	1.206
	2017~2018	0.612	0.593	1.033
	2018~2019	0.911	0.931	0.978
	2019~2020	0.747	0.909	0.822
DHOFAR BEVERAGES (DBCI)	2015~2016	0.563	1.000	0.563
	2016~2017	0.920	0.825	1.115
	2017~2018	2.043	1.212	1.685
	2018~2019	0.725	1.000	0.725
	2019~2020	0.892	1.000	0.892
JAZEERA STEEL PROD (ATMI)	2015~2016	0.944	1.025	0.921
	2016~2017	1.198	0.964	1.242
	2017~2018	1.084	1.037	1.045
	2018~2019	1.142	1.000	1.142
	2019~2020	0.772	1.000	0.772
DHOFAR CATTLE (DCFI)	2015~2016	1.103	1.000	1.103
	2016~2017	0.296	0.395	0.748
	2017~2018	1.129	1.027	1.099
	2018~2019	1.427	1.296	1.101
	2019~2020	0.973	1.028	0.947
Gulf International Chemicals SAOG	2015~2016	0.678	0.762	0.890
	2016~2017	0.948	0.977	0.970
	2017~2018	0.922	0.809	1.140
	2018~2019	0.956	0.762	1.255
	2019~2020	0.864	1.074	0.804

Source: Authors' calculation

Table B1 Firm-wise and year-wise productivity, efficiency and technical change over the study period (continued)

DMUs	*Year*	*TFP*	*EC*	*TEC*
Voltamp Energy SAOG	2015~2016	1.092	1.237	0.883
	2016~2017	1.009	1.046	0.965
	2017~2018	1.055	1.065	0.991
	2018~2019	0.922	0.956	0.964
	2019~2020	0.876	0.830	1.056
A'SAFFA FOODS SAOG	2015~2016	0.930	1.038	0.897
	2016~2017	1.009	0.884	1.142
	2017~2018	0.967	0.890	1.087
	2018~2019	0.802	0.756	1.062
	2019~2020	0.982	1.086	0.904
SALALAH MILLS (SFMI)	2015~2016	0.896	1.000	0.896
	2016~2017	0.833	0.901	0.926
	2017~2018	0.906	0.928	0.976
	2018~2019	1.047	0.949	1.103
	2019~2020	1.009	1.049	0.962
MAJAN GLASS (MGCI)	2015~2016	0.876	1.030	0.851
	2016~2017	0.809	0.758	1.067
	2017~2018	1.272	1.236	1.029
	2018~2019	2.289	1.966	1.164
	2019~2020	1.194	1.300	0.918
National Aluminium Products Company SAOG	2015~2016	0.873	0.940	0.929
	2016~2017	1.289	1.243	1.037
	2017~2018	1.361	1.315	1.035
	2018~2019	0.917	0.750	1.224
	2019~2020	0.931	0.989	0.942
Muscat Thread MILL (MTMI)	2015~2016	0.998	1.077	0.926
	2016~2017	1.112	1.231	0.904
	2017~2018	0.975	0.847	1.151
	2018~2019	1.031	0.812	1.271
	2019~2020	0.810	0.976	0.829
GULF MUSHROOM PRODUCTS (GMPI)	2015~2016	0.819	0.960	0.854
	2016~2017	0.874	0.762	1.147
	2017~2018	1.226	1.481	0.828
	2018~2019	1.069	0.882	1.213
	2019~2020	0.853	1.085	0.787
Gulf Stone Company SAOG	2015~2016	1.071	1.180	0.907
	2016~2017	0.672	0.589	1.140

Source: Authors' calculation

Table B1 Firm-wise and year-wise productivity, efficiency and technical change over the study period (continued)

DMUs	*Year*	*TFP*	*EC*	*TEC*
Gulf Stone Company SAOG	2017~2018	0.968	0.864	1.120
	2018~2019	0.828	0.696	1.189
	2019~2020	0.858	0.973	0.882
The National Detergent Company SAOG	2015~2016	0.974	1.104	0.882
	2016~2017	1.020	0.994	1.026
	2017~2018	0.963	0.894	1.077
	2018~2019	0.958	0.796	1.203
	2019~2020	1.025	1.141	0.898
National Mineral Water Company SAOG	2015~2016	0.838	1.000	0.838
	2016~2017	1.022	1.000	1.022
	2017~2018	0.899	0.835	1.077
	2018~2019	0.821	0.649	1.265
	2019~2020	1.019	1.212	0.842
Oman Cables Industry (SAOG)	2015~2016	0.880	1.000	0.880
	2016~2017	0.995	1.000	0.995
	2017~2018	1.028	1.000	1.028
	2018~2019	0.814	0.854	0.953
	2019~2020	0.908	0.913	0.994
Oman Flour Mills Company (SAOG)	2015~2016	0.727	1.000	0.727
	2016~2017	0.945	1.000	0.945
	2017~2018	0.977	0.997	0.979
	2018~2019	1.311	1.003	1.308
	2019~2020	0.894	1.000	0.894
OMAN PACKAGING Company (OPCI)	2015~2016	0.999	1.115	0.896
	2016~2017	1.001	1.040	0.963
	2017~2018	0.984	0.915	1.076
	2018~2019	1.004	0.738	1.361
	2019~2020	0.941	1.147	0.821
Oman Refreshment Company (SAOG)	2015~2016	0.953	1.000	0.953
	2016~2017	0.993	1.000	0.993
	2017~2018	0.980	0.967	1.013
	2018~2019	0.866	0.907	0.955
	2019~2020	1.188	1.141	1.041
Sweets of Oman (SAOG)	2015~2016	0.829	0.846	0.980
	2016~2017	0.839	0.911	0.921
	2017~2018	0.890	0.797	1.117

Source: Authors' calculation

Table B1 Firm-wise and year-wise productivity, efficiency and technical change over the study period (continued)

DMUs	*Year*	*TFP*	*EC*	*TEC*
Sweets of Oman (SAOG)	2018~2019	1.051	0.842	1.248
	2019~2020	0.466	0.567	0.823
Al Maha Ceramics (SAOG)	2015~2016	0.981	1.160	0.845
	2016~2017	0.932	0.857	1.088
	2017~2018	0.980	0.915	1.070
	2018~2019	0.958	0.722	1.327
	2019~2020	1.081	1.505	0.718
Oman Chlorine (SAOG)	2015~2016	1.012	1.854	0.546
	2016~2017	1.054	0.647	1.631
	2017~2018	1.046	1.030	1.016
	2018~2019	0.846	0.875	0.967
	2019~2020	0.938	1.077	0.871
Oman Cement Company (SAOG)	2015~2016	0.913	1.728	0.528
	2016~2017	1.094	0.575	1.902
	2017~2018	0.927	1.113	0.832
	2018~2019	1.036	1.030	1.005
	2019~2020	1.092	1.189	0.919
Raysut Cement Company (SAOG)	2015~2016	0.915	2.018	0.454
	2016~2017	0.744	0.403	1.846
	2017~2018	1.327	1.330	0.998
	2018~2019	0.987	1.010	0.978
	2019~2020	0.930	1.131	0.822
Dhofar Fisheries and Food Industries	2015~2016	0.886	1.009	0.879
	2016~2017	0.964	0.986	0.979
	2017~2018	1.143	1.067	1.071
	2018~2019	0.866	0.785	1.104
	2019~2020	0.937	1.012	0.926

Source: Authors' calculation