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Evidence of Malaysian Company Performance using Copula and Stochastic Frontier Analysis During the COVID-19 Pandemic

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ABSTRACT

Traditional stochastic frontier analysis (SFA) assumes error independence, potentially leading to estimation and efficiency score errors. The purpose of this paper is to introduce the assumption of dependent errors into SFA to rank the performance of 12 Malaysian companies. In 2019 and 2020, during the global COVID-19 outbreak, the shockwaves it sent through various sectors, including healthcare and transportation, were profound. This study assesses company efficiency performance using the copula stochastic frontier analysis (CSFA) model. Seven Archimedean copulas are considered, and the most suitable copula is selected based on the lowest AIC (Akaike Information Criterion) value. The Cot copula, with an AIC value of -19.707, emerges as the best model. The results also reveal a relationship between random errors and inefficiency errors, as well as evidence that COVID-19 contributes to business inefficiency. According to the Cot copula results, Eita Resources Berhad (0.995), My E.G. Services Berhad (0.994), and KPJ Healthcare Berhad (0.857) are the top-performing companies, while Pansar Berhad (0.316), Suria Capital Holdings Berhad (0.319), and Hap Seng Consolidated Berhad (0.411) are the least efficient ones. Therefore, the primary contribution of this study is the proposition that the Cot copula and SFA are appropriate models for analyzing efficiency results. CSFA is a highly accurate model as it accounts for external factors, or random noise, in efficiency estimation and acknowledges the assumption of dependent errors in SFA, making it more realistic for real-world applications.

1. Introduction

Performance evaluation is a critical concern for various stakeholders within a company, such as business analysts, creditors, investors, and financial management. As highlighted by Riedl *et al.,* [1], measuring company performance serves to assess its success, current status, identify underlying

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issues, and explore potential solutions. Companies with poor performance face increased levels of competition and are more likely to run into financial difficulties, whereas high-performing companies can provide new employment possibilities and add to their shareholders' wealth. Because of this, choosing the appropriate methods of analysis is important, so that the results gained are more accurate and can contribute to the planning of strategies and the making of better judgements. When discussing how to measure a company's performance, previous research often refers to the measurement of efficiency. In 1957, Farrell [2] offered a new measurement of efficiency since the research of Debreu [3] and Koopmans [4] may have been improved. A company's efficiency can be divided into two main parts: first, technical efficiency, which is the business's ability to maximise output given a certain set of inputs; and second, allocation or price efficiency, which is the company's ability to make optimal use of inputs given a set of prices. Both of these components contribute to a company's overall efficiency. According to Sena [5], efficiency performance evaluation can be described as decision making unit (DMU) efficiency in meeting specific economic goals, such as producing at least cost, generating maximum production outcomes, or maximising profit. Other examples of these types of goals include generating maximum production results or maximising profit.

The parameterized technique (economic approach) and the non-parametric method (mathematical programming) are the two types of frontiers estimating approaches that are used in the process of measuring efficiency performance [6]. The estimation method is also a point of contention since some researchers prefer parametric approaches [7], while others prefer non-parametric methods [8]. The basic idea behind the frontier method approach to production, according to Batiese [9], is to figure out how inputs are used to make the best output based on the technical efficiency score that DMU gets. So, technical efficiency in the production process is the ability of a DMU or a company to get the most output from a given set of inputs [10]. Sahudin *et al.,* [11] says that producers (DMU) or companies are fully efficient when they do well and are above the frontier, where the efficiency number is one. But when they don't do their best, they are said to be inefficient, and their score for efficiency is less than one.

Charnes *et al.,* [12] used a variety of inputs and outputs and turned them into a mathematical programming model called the data envelopment analysis (DEA) model. The DEA model is an illustration of bound or boundary-based non-parametric efficiency estimates. According to Siew *et al.,* [13], the DEA model has no constraints on the shape of functions associated with inputs and outputs, requires few assumptions, and is an irregular border model. While Murillo-Zamorano [14] claims that technical inefficiency can be found in the gap between DMU's actual production performance and its maximum production and the gap or difference in performance, all of which are under the agent's control, but Coelli *et al.,* [15] says that the performance of DMU is also affected by factors that are out of the agent’s hands. These include the competitive environment, the weather, luck, political instability, socio-economic factors, demographics, and uncertainty, which cannot be directly linked to technical inefficiency. So, this method's biggest flaw is that it doesn't take random factors (noise) into account for calculating the technical efficiency.

Unlike the DEA model, the SFA model provided in Aigner *et al.,* [16], Meeusen and Broeck [17], and Battese and Corra [18] is able to distinguish between two types of errors: those caused by external, uncontrollable factors (random error) and those generated by internal, inefficiency error. One of the benefits of the SFA production model, as stated by Tibprasorn *et al.,* [19], is that it can help businesses figure out if the gap between their actual output and their potential output (as represented by the production frontier function) is due to a lack of best practises or to random error. The influence of weather, natural disasters, geography, and machine performance are only some examples of the kinds of dispersed, random, and out-of-control shocks that contribute to this random component. In agriculture, for instance, unpredictable events like bad weather can reduce the chances of a producer reaching production efficiency (maximum output). Since the SFA model takes into account a number of stochastic factors when determining a company's technical efficiency, the production concept it employs is considered more realistic. Researchers using the SFA model to estimate efficiency assume that technical inefficiency errors and random errors are not related to one another. But this assumption is not accurate to use, because these two errors are interrelated.

For example, in terms of the company's productivity, the COVID-19 surprised the entire world by having a devastating effect on healthcare, the economy, transportation, and other sectors across the globe. Numerous studies have looked at how this pandemic has affected business output [20-23]. Chinese company financial data was used to analyse the effect of COVID-19 on business performance [24]. According to their research, the COVID-19 pandemic severely hampered the economic output of the country's businesses by decreasing investment and overall income. The tourism, hospitality, and transportation sectors are all being hit hard by this pandemic. According to their research, business performance dropped dramatically in the first quarter of 2020. From an economic point of view, Seetharaman [25] says that one of COVID-19's effects is a sudden drop in both demand and supply. A decrease in demand has resulted from a decrease in spending and investment, which has been a result of businesses closing down to stop the pandemic. The slowdown in the economy is also a result of domestic factors, such as COVID-19 control measures and movement control. On a large scale, the closing of businesses and services and restrictions on movement and travel have a big effect on the amount of money spent and invested in the country [26].

Previous studies have also found that the two main types of error (inefficiency and random errors) depend on each other. El Mehdi and Hafner [27] apply the copula and SFA models to estimate the technical efficiencies of Moroccan municipalities, defining operating receipts as input and financial autonomy as output. Tibprasorn *et al*., [28] and Tibprasorn *et al*., [29] used copula and the SFA model to estimate stock efficiencies on the Stock Exchange of Thailand (SET50). Tansuchat [30] analysed sea salt production and compared the technical efficiency level and the technology gap between traditional technology and High-Density Polyethylene Geomembranes (HDPE GMB) technology in the Phetchaburi province using a copula-based meta-stochastic frontier technique. Li *et al.,* [31] investigates the consequences of ignoring any dependency in error components or heterogeneity in the SFA, and proposes a copula based SFA with heterogeneity to resolve such weaknesses based on a simulation study to prove its superiority over the traditional SFA, followed by an empirical application on a sample of rice producers from northern Thailand. Many issues have happened in Malaysia that were out of the company's control. Disease outbreaks like COVID-19, political problems, and changes in government policies or programmes are all examples of issues that could make it hard for a company to manage its supplies well. Therefore, this study aims to propose the best Copula SFA (CSFA) to model the dependency between random error and inefficiency error and rank the selected Malaysian companies’ performance based on their efficiency score. This model's ranking is more accurate because it takes uncontrollable factors like natural disasters (COVID-19) into account when calculating efficiency and uses error assumptions that are more reasonable in the real world. Additionally, copula-based company efficiency studies are rare, especially in Malaysia. This article is written in this flow: Section 2 will summarise all the data and methods used, followed by a discussion of the results, and the last section will be the conclusions and recommendations for future studies.

2. Methodology

This research calculates the technical efficiency score and rank of the selected companies listed on Bursa Malaysia. The data covered a period of two years, from 2019 to 2020. Secondary data were primarily culled from company annual reports retrieved from Thomson Reuters' DataStream for this study. MATLAB was used to calculate the efficiency score. Table 1 shows the 12 chosen listed companies. Industrial products and services (5 companies), transportation and logistics (3 companies), energy (1), construction (1), technology (1), and healthcare (1) were among the six selected industries.

Table 1
The selected Malaysian companies

DMU	Companies	Sector
1	My E.G. Services Berhad	Technology
2	George Kent (Malaysia) Berhad	Construction
3	Pansar Berhad	Industrial Products and Services
4	Deleum Berhad	Energy
5	Eita Resources Berhad	Industrial Products and Services
6	Freight Management Holding Berhad	Transportation and Logistics
7	Hap Seng Consolidated Berhad	Industrial Products and Services
8	Harbour-Link Group Berhad	Transportation and Logistics
9	KPJ Healthcare Berhad	Health Care
10	Luxchem Corporation Berhad	Industrial Products and Services
11	Pantech Group Holdings Berhad	Industrial Products and Services
12	Suria Capital Holdings Berhad	Transportation and Logistics

The SFA model was used to calculate the value of the efficiency score based on financial ratios. It includes asset turnover (AT), market capitalization (MC), debt-to-equity ratio (DE), and returns on equity (ROE). This research involves the following steps:

i. **Step 1:** Select the inputs and outputs. Three inputs and one output were selected, which are described as follows: The value of a company's sales and income as compared to the value of its assets, as determined by AT, is input 1. It is used to measure how well the assets are used to make money. Input 2, MC, shows the size of a company, which is known to be the most important factor in many things, including risk, which investors are interested in. Input 3, the DE ratio, is used in this study to measure a company's leverage. Output, or ROE, shows how much profit a company made compared to the total shareholders' equity recorded on balance sheets.

ii. **Step 2**: Identify the production function types in use. These functions show the link between the number of inputs and the number of outputs. The Cobb-Douglas production model is used to measure a company's efficiency. It is written as:

$$ln(ROE)_{it} = \beta_0 + \beta_1 ln(AT)_{it} + \beta_2 ln(MC)_{it} + \beta_3 ln(DE)_{it} + v_{it} - u_{it} \quad (1)$$

where subscripts i and t represent the i^{th} company (DMU) for $i = 1,2, \dots \dots ,12,$ and t^{th} year of observation for $t = 1,2$. In representing the natural logarithm, β is a vector of unknown parameters to be estimated. The v_{it} term corresponds to random error, statistical noise, measurement error, and other random events that are beyond the company's control and it is assumed to be independently and identically distributed (i.i.d) normal random variables with zero means and variances; $v_{it} \sim N(0, \sigma_v^2)$. The u_{it} term is a nonnegative random variable associated with technical inefficiency in production and is assumed to be independently and identically distributed (i.i.d).

iii. **Step 3:** For this study, it was assumed that v_{it} and u_{it} had dependently distributed each other. Half-normal distribution was picked for u_{it} and normal distribution for v_{it}. When v_{it} and u_{it} rely on each other, copula will use to join the distributions of both errors. This model is called copula SFA (CSFA). For the assumption of technical inefficiency error, $u_{it} = u_i$ if the technical inefficiency error has a constant effect (time-invariant) over time. Let G_1 and G_2 denote the distribution functions of u and v respectively, and H be the joint distribution function of u and v. Then, by the Sklar theorem, there is a copula, C_θ which satisfies in relation, $H(u, v) = C_\theta(G_1(u), G_2(v))$, and so its joint density function is as follows:

$$h(u, v) = g_1(u)g_2(v)C_\theta(G_1(u), G_2(v)) \tag{2}$$

As $\varepsilon = v - u$, by the marginal distribution of h, we get:

$$h(\varepsilon) = \int_0^{+\infty} g_1(u)g_2(u + \varepsilon)C_\theta(G_1(u), G_2(u + \varepsilon)) \tag{3}$$

iv. **Step 4:** Estimate the SFA model using the maximum likelihood estimator (MLE). Copulas were used to model the marginal distributions for their dependence structure.

v. **Step 5:** The DMU's (companies) technical efficiency score is calculated after estimating stochastic frontier models. Technical efficiency is defined as follows:

$$TE = \frac{1}{h(\varepsilon)} \int_{\Re^+} exp\{-u\} h(u, \varepsilon) \tag{4}$$

The copula used is from the Archimedean group. Seven copula functions were selected for this study: Clayton, A12, Gumbel, Csch, Coth, Cot, and Product. Three copulas have a trigonometric and hyperbolic generator, and they are more flexible in modelling dependence structures. The Cot copula function has a trigonometric generator and was proposed by Pirmoradian and Hamzah [32]. Also, the Csch copula and Coth copula families have hyperbolic generators and were proposed by Hasan and Hamzah [33] and Najjari *et al.,* [34], respectively.

vi. **Step 6:** Once the technical efficiency score using the copula SFA model is obtained, the criterion information used in this study is the Akaike Information Criterion (AIC), which can be calculated as follows:

$$AIC = (-2LL + 2m)/N \tag{5}$$

where, LL is the likelihood log for the model, m is the estimated number of parameters, and N is the sample size for the data. AIC is used to determine the best model. The model that has a small AIC value will be considered the best model.

3. Results and Discussions

Table 2 presents the parameter θ and Kendall τ for six copulas derived from the Archimedean family, specifically Clayton, A12, Gumbel, Csch, Coth, and Cot, for both the years 2019 and 2020. Notably, in the case of the Product copula, the parameter θ assumes a value of one, signifying an assumption of independence between the variables.

The comprehensive analysis of the Kendall τ values within Table 2 unequivocally establishes a correlation between the variables examined in this study, specifically the technical inefficiency error, u and random error, v. Consequently, it is advisable to incorporate the assumption of dependence between these two variables into the Stochastic Frontier Analysis (SFA) model.

Table 2
Parameter θ and Kendall τ values for 2019 and 2020

Copula	Kendall τ	P	2019	2020	Average
Clayton	$\frac{\theta}{\theta+2}$	θ	3.123	3.211	3.167
		τ	0.610	0.616	0.613
A12	$1-\frac{2}{3\theta}$	θ	5.171	3.828	4.499
		τ	0.871	0.826	0.852
Gumbel	$\frac{\theta-1}{\theta}$	θ	9.491	8.028	8.760
		τ	0.895	0.875	0.886
Csch	$\frac{\theta}{\theta+2}$	θ	1.462	2.072	1.767
		τ	0.422	0.509	0.469
Coth	$1+\frac{2}{\theta^2}-\frac{2}{\theta}\coth(\theta)$	θ	1.245	5.769	3.507
		τ	0.393	0.713	0.591
Cot	$1-\frac{8}{\pi^2\theta}$	θ	4.032	3.471	3.751
		τ	0.799	0.766	0.784

Subsequently, seven distinct copula models from the Archimedean family, specifically Clayton, A12, Gumbel, Csch, Coth, Cot, and Product, are employed to calculate the efficiency scores, which are presented in Table 3. The results reveal that the efficiency scores for each of the 12 companies exhibit remarkable uniformity across all the specified copula types.

Table 3
Average company efficiency based on copula groups for 2019 and 2020

DMU	Clayton	A12	Gumbel	Csch	Coth	Cot	Product
1	0.998	0.990	0.999	0.997	0.998	0.994	0.998
2	0.807	0.808	1	0.873	0.900	0.757	0.917
3	0.340	0.339	0.208	0.295	0.286	0.316	0.281
4	0.438	0.437	0.296	0.373	0.372	0.462	0.372
5	0.997	0.997	0.998	1	0.999	0.995	0.999
6	0.475	0.475	0.457	0.462	0.458	0.505	0.456
7	0.354	0.348	0.308	0.318	0.320	0.411	0.319
8	0.548	0.546	0.565	0.551	0.551	0.555	0.550
9	0.629	0.624	0.704	0.578	0.597	0.857	0.604
10	0.791	0.786	0.373	0.608	0.576	0.770	0.560
11	0.591	0.590	0.864	0.623	0.635	0.673	0.640
12	0.345	0.353	0.830	0.437	0.484	0.319	0.517

In Table 4, the copula group's average efficiency scores for the years 2019 and 2020 are presented. These scores, calculated using copula analysis, indicate that for the year 2020, the efficiency scores surpass the 60% threshold. When considering the two-year aggregate average efficiency score, only two copula variants (Coth and Csch) exhibit values below 60%, whereas the other five (Clayton, A12, Gumbel, Cot, and Product) display values exceeding 60%.

Table 4
Average company efficiency by year and copula type for 2019 and 2020

N=12	2019	2020	Average
Clayton	0.596	0.623	0.609
A12	0.593	0.623	0.608
Gumbel	0.633	0.634	0.633
Csch	0.567	0.619	0.593
Coth	0.567	0.629	0.598
Cot	0.645	0.624	0.635
Product	0.567	0.635	0.601

The company rankings are determined based on the computed scores. Table 5 presents the rankings for all twelve DMU selections in both 2019 and 2020. The results indicate minimal disparity in the rankings when considering the various copula types employed. To ascertain the most suitable copula model for the data, the Akaike Information Criterion is employed for both the 2019 and 2020 datasets.

Table 5
Ranking of companies based on copula groups for 2019 and 2020

DMU	Rank						
	Clayton	A12	Gumbel	Csch	Coth	**Cot**	Product
1	1	2	2	2	2	2	2
2	3	3	1	3	3	5	3
3	12	12	12	12	12	12	12
4	9	9	11	10	10	9	10
5	2	1	3	1	1	1	1
6	8	8	8	8	9	8	9
7	10	11	10	11	11	10	11
8	7	7	7	7	7	7	7
9	5	5	6	6	5	3	5
10	4	4	9	5	6	4	6
11	6	6	4	4	4	6	4
12	11	10	5	9	8	11	8

Table 6 presents the AIC values corresponding to each copula distribution. The selection of the Cot copula as the optimal model for the 2019-2020 data panel is supported by its possession of the smallest AIC value. These results validate the superiority of the Cot copula in characterizing the interdependence of errors within the framework of Stochastic Frontier Analysis (SFA).

Table 6
Estimated AIC for CSFA models for 2019 and 2020

Copula	Clayton	A12	Gumbel	Csch	Coth	**Cot**	Product
Log L	16.666	16.621	16.735	16.535	16.598	16.854	16.120
AIC	-19.332	-19.242	-19.470	-19.071	-19.195	-**19.707**	-18.240

Analysis using the Cot copula (Table 5) reveals that Eita Resources Berhad (DMU5), My E.G. Services Berhad (DMU1), and KPJ Healthcare Berhad (DMU9) occupy the top three positions in terms of performance. Conversely, DMU7 (Hap Seng Consolidated Berhad), DMU12 (Suria Capital Holdings Berhad), and DMU3 (Pansar Berhad) exhibit the poorest performance among the selected companies. Furthermore, this ranking obtained through the SFA copula model (Cot copula) underscores its validity. For instance, Suria Capital Holdings Berhad, situated at the bottom tier of the 12 chosen companies, operates within the transportation industry. The analysis suggests that government measures, such as movement restrictions during the pandemic, may have adversely affected this company's performance. Reduced public transit usage in the pandemic season likely contributed to its efficiency downturn.

The COVID-19 pandemic has compelled nations and organizations worldwide to overhaul their business operations, with some countries implementing Movement Control Orders (MCO) to curtail the virus's spread. In the case of Malaysia, during the MCO, all non-essential businesses were shuttered, interstate travel was restricted, and daily necessities were subject to limitations [35]. However, amid this ongoing pandemic, select enterprises, including KPJ Healthcare Berhad, have thrived. KPJ Healthcare Berhad has distinguished itself as one of the most adept businesses, substantiated by its ranking in this study. Its success is attributed to its status as a private hospital delivering indispensable healthcare services to the general populace. My E.G. Service Berhad, securing the second position, also boasts an impressive operational efficiency track record. Significantly, the company offers a gamut of technologically driven services in consistent demand, even amidst a pandemic, encompassing license renewals, electronic bill settlements, and online information services like traffic violation fine reviews. Noteworthy is the model championed by Smith [36], integrating copula functions, which emerges as the optimal approach. Copula functions prove highly effective in capturing rank correlation and tail dependence between dual error components, thereby enhancing the adaptability of stochastic frontier analysis. Research aimed at precisely elucidating the repercussions and consequences of the COVID-19 Pandemic and MCO is of paramount importance. This research forms the cornerstone for the formulation and meticulous refinement of essential guidelines and standardized operating procedures [37].

4. Conclusions

In summary, this paper has effectively achieved its objective of determining the positions of 12 Malaysian companies throughout the pandemic period by employing copula and Stochastic Frontier Analysis (SFA) models. The results highlight a correlation between random errors and inefficiency errors, with the Cot copula emerging as the most suitable copula model. This underscores how unforeseen events like the COVID-19 pandemic can impact a company's inefficiency. Consequently, the CSFA model, specifically employing the Cot Copula, offers a meaningful framework for evaluating company efficiency, particularly when distinguishing between industries affected and unaffected by the pandemic. The incorporation of dependency assumptions in the SFA model for both random and technical inefficiency errors enhance its realism.

The primary contribution of this study lies in proposing a robust model for measuring efficiency performance while considering relevant assumptions. Previous studies have frequently applied SFA to gauge the efficiency of Malaysian companies but often without acknowledging the potential relationship between random errors (e.g., COVID-19) and inefficiency errors. Hence, the inclusion of dependency assumptions between these two errors, facilitated by copula usage, represents an essential advancement. Although the computational intensity of copula methods is acknowledged, their utilization is necessary for obtaining precise efficiency values, models, and assumptions without compromising cost-effectiveness and decision-making.

In future research endeavours, the exploration of distinct copula families within the SFA framework should be pursued to gauge a company's efficiency comprehensively. Additionally, the inclusion of alternative inputs and outputs in the SFA model may yield varied estimates. Researchers should also consider experimenting with diverse distributions for inefficiency errors to enrich the analytical landscape.

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