Optimizing Short-Term Forecasting of Rice Stock-Commercial During the COVID-19 Pandemic using GA-Based Holt-Winters Method

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Abstract

In the current era, one of the key challenges in utilizing the Holt-Winters Method of forecasting is the accurate selection of smoothing coefficients. To address this issue, researchers have explored an optimization approach that aims to minimize forecasting errors, such as Mean Squared Errors (MSE) or Mean Absolute Deviation (MAD). This paper presents a novel methodology that employs a Genetic Algorithm (GA) to optimize the forecasting error by determining the optimal smoothing coefficients for the Holt-Winters Method. The objective value of the optimization problem is the Mean Square Error (MSE), which serves as a measure of the accuracy of the forecast. To evaluate the effectiveness of the proposed approach, actual test cases based on rice stock commercial commodity in the Philippines during the COVID-19 pandemic were utilized. The paper examines different variants of the Holt-Winters Method and assesses their suitability for capturing the characteristics of the rice stock data. The findings indicate that an additive seasonal effect is more appropriate for modeling the seasonal patterns observed in the rice stock data. Furthermore, the performance of the proposed GA-based approach is compared to other forecasting models to ascertain its efficacy. The results demonstrate promising outcomes, suggesting that the GA-based optimization approach for determining the smoothing coefficients in the Holt-Winters Method improves the accuracy of rice stock forecasting during the COVID-19 pandemic.

Keywords
Forecast error, Genetic Algorithm, Holt-Winters, Optimization, Rice stock prediction

1. Introduction
The COVID-19 pandemic has had a significant impact on various sectors, including the rice stock commodity in the Philippines. The pandemic disrupted global supply chains, affected labor availability, and created logistical challenges, all of which had repercussions on the rice market in the country. During the pandemic, the Philippines, like many other nations, faced uncertainties and concerns regarding food security. Hilhorst, Mijatović, and Ramos (2021) presents a comprehensive review of the impacts of the COVID-19 pandemic on food systems worldwide. It

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explores the vulnerabilities of food systems and the challenges encountered in ensuring food security during the pandemic. They highlight that the COVID-19 pandemic has exposed and intensified existing vulnerabilities in global food systems. They discuss the disruption of agricultural production, supply chains, and markets due to various factors, including lockdown measures, trade restrictions, labor shortages, and reduced access to inputs. These disruptions have led to food price volatility, reduced incomes for farmers, and increased food insecurity for vulnerable populations.

Rice, being a staple food, became a critical commodity, and ensuring an adequate rice stock became a priority for the government and policymakers. Aggarwal and Joshi (2020) provide an overview of the impacts of the COVID-19 pandemic on agriculture, food systems, and rural livelihoods in Asia, with a specific focus on the Philippines. The article highlights the challenges faced in maintaining food security during the pandemic and discusses strategies employed to mitigate the effects on the agricultural sector. Also, they emphasize the disruptions caused by COVID-19 in agricultural production, supply chains, and markets. Lockdown measures and restrictions on movement have hindered farming activities, including planting, harvesting, and transportation of agricultural commodities. These disruptions have led to reduced production and increased post-harvest losses, affecting the availability and affordability of food. In addition, they discuss the adverse impacts on rural livelihoods, particularly for small-scale farmers and vulnerable communities. Loss of income and employment opportunities has exacerbated poverty and food insecurity.

The article provides a comprehensive overview of the impacts of COVID-19 on agriculture, food systems, and rural livelihoods in Asia, with a specific focus on the Philippines. It emphasizes the challenges faced in maintaining food security and highlights the importance of coordinated policy responses to mitigate the effects of the pandemic on the agricultural sector and ensure the resilience of rural communities. Meanwhile, the paper by Balisacan, Fuwa, and Mapa (2020) provides a detailed analysis of the short-run impacts and medium-term challenges faced by Philippine agriculture, with a specific emphasis on the rice sector, due to the COVID-19 pandemic. The paper investigates the disruptions in the rice supply chain and proposes policy measures to mitigate the challenges and ensure food security. The paper sheds light on the short-run impacts and medium-term challenges faced by Philippine agriculture, specifically focusing on the rice sector, due to the COVID-19 pandemic. It underscores the need for targeted policy measures to address disruptions in the rice supply chain, ensure food security, and support the livelihoods of farmers and rural communities during and beyond the pandemic

The pandemic led to disruptions in rice production, transportation, and distribution channels. Restrictions on movement, quarantine measures, and labor shortages posed challenges to farmers, affecting their ability to plant, harvest, and transport rice. Moreover, disruptions in international trade also impacted rice imports, which play a crucial role in meeting domestic demand. These disruptions, coupled with panic-buying and stockpiling behavior by consumers, created fluctuations in rice prices and supply chain disruptions. The government implemented measures to stabilize the rice stock commodity, including promoting local production, ensuring access to inputs for farmers, facilitating transportation, and monitoring market prices. The pandemic highlighted the importance of maintaining a resilient and secure rice stock in the Philippines. It underscored the need for effective forecasting and management strategies to anticipate and respond to potential disruptions in the future. Rice stock prediction refers to the process of forecasting the future levels of rice stock, which refers to the quantity of rice available in storage or inventory. It is an important aspect of agricultural planning and food security management as it helps policymakers, traders, and other stakeholders make informed decisions regarding rice production, distribution, and import/export activities.

The Holt-Winters method, also known as the triple exponential smoothing method, is a popular time series forecasting technique that has been applied to various domains, including the analysis of rice stock in the Philippines. This method is particularly suitable for datasets with trend and seasonality components, making it relevant for modeling and predicting rice stock patterns. The Holt-Winters method extends the simple exponential smoothing technique by incorporating additional components: level, trend, and seasonality. These components capture the underlying patterns and variations observed in the rice stock data over time, enabling more accurate forecasting. Researchers have been exploring various methodologies and models, such as the Holt-Winters Method to optimize forecasting accuracy and enhance decision-making regarding the rice stock commodity during the pandemic and beyond, these efforts aim to ensure food security, stabilize prices, and meet the rice demands of the population during challenging times. The applicability of the Holt-Winters Method in rice stock prediction lies in its ability to handle seasonal data, which is often observed in the rice sector due to the influence of factors such as planting and harvesting seasons, market demand fluctuations, and government policies. The model takes into account the seasonal variations and adjusts the forecasts accordingly.

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1.1 Objectives

The primary objective is to generate accurate forecasts of rice stock levels during the pandemic. By analyzing historical data and incorporating trend and seasonality components, the Holt-Winters method can provide reliable predictions. Accurate forecasts enable policymakers, traders, and other stakeholders to make informed decisions regarding rice production, imports, and distribution, ensuring sufficient supply to meet the population's needs. Moreover, The Holt-Winters method can assist in effectively managing the rice supply chain during the pandemic. By forecasting future rice stock levels, stakeholders can optimize procurement, storage, and distribution strategies. This helps prevent supply chain disruptions, reduces wastage, and ensures a steady flow of rice to consumers. In addition, efficient inventory management is crucial during the pandemic to avoid stock outs or excess rice stock. The Holt-Winters method helps in estimating the optimal level of rice stock required to meet demand while minimizing carrying costs. This enables stakeholders to maintain an appropriate buffer stock, reducing the risk of shortages or oversupply. Accurate forecasting using the Holt-Winters method aids in stabilizing rice prices during the pandemic. By anticipating changes in rice stock levels, stakeholders can take appropriate actions to balance supply and demand, preventing price fluctuations that may occur due to shortages or surpluses. Price stability contributes to ensuring affordable access to rice for consumers. This paper will use the Holt-Winters Method with Genetic Algorithm (GA). The paper aims to produce accurate predictions using GA in optimizing the Mean Squared Error (MSE) that will generate recommended smoothing coefficients of the Holt-Winters Model. Traditional and proposed GA-Based model were applied in the test cases to evaluate the robustness of the proposed method.

2. Literature Review

During Pandemic, Holt-Winters have been extensively used in COVID-19 cases as primary topic. The article by Montemayor and Maala (2021) focuses on the application of time series models, including the Holt-Winters Methodology, for short-term forecasting of COVID-19 cases in the Philippines. The paper aims to develop accurate forecasting models to assist in managing and mitigating the spread of the virus. Meanwhile, the article by Salvaña, Pugoy, and Suanding (2021) focuses on the application of time series analysis, including the Holt-Winters Methodology, and artificial intelligence techniques for COVID-19 forecasting in the Philippines. They propose a hybrid model that integrates the Holt-Winters Methodology with artificial intelligence techniques, such as neural networks and machine learning algorithms. They utilize historical data on COVID-19 cases, including confirmed cases, recoveries, and deaths, to train and validate the model. The findings of the research demonstrate that the hybrid model, incorporating time series analysis and artificial intelligence techniques, yields accurate forecasts of COVID-19 cases in the Philippines.

The model effectively captures the underlying patterns and trends, allowing for reliable short-term and long-term predictions. The paper also highlights the importance of data quality, feature selection, and model training in enhancing the forecasting accuracy. They emphasize the need for continuous data updates and incorporating external factors, such as government interventions and public health measures, to improve the model's performance. Moreover, the article by Pineda, Maniquiz, and Sarmiento (2021) focuses on the development of a hybrid ensemble model for short-term forecasting of COVID-19 cases in the Philippines. The paper combines the Holt-Winters Methodology with other models to improve the accuracy of predictions and support effective decision-making during the pandemic. In the paper, the authors propose a hybrid ensemble model that incorporates the Holt-Winters Methodology with other models, such as autoregressive integrated moving average (ARIMA) and support vector regression (SVR). They utilize historical data on COVID-19 cases, including daily confirmed cases, recoveries, and deaths, to train and validate the model. The findings of the research demonstrate that the hybrid ensemble model effectively improves the accuracy of short-term forecasts of COVID-19 cases in the Philippines. By combining the strengths of different models, the ensemble model captures the complex dynamics and underlying patterns of the pandemic, leading to more reliable predictions.

Moreover, some related literature used Holt-Winters to rice stock prediction, among are the research presented by Ligon and Tauli (2021) concentrates on the application of the Holt-Winters Methodology for forecasting rice stock in the Philippines during the pandemic. The paper aims to assess the accuracy and performance of the model in predicting rice stock levels, which is crucial for ensuring food security and making informed policy decisions. This paper highlights the significance of reliable rice stock forecasts in managing the supply and demand dynamics of the staple crop. They emphasize the need for accurate predictions, particularly during the pandemic when disruptions in the agricultural sector and supply chains pose challenges to food security. In the paper, the authors employ the Holt-Winters Methodology to forecast rice stock in the Philippines. They utilize historical data on rice production, imports,

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exports, and consumption to train and validate the model. The performance of the Holt-Winters Methodology is evaluated based on its ability to accurately predict rice stock levels. The findings of the research demonstrate that the Holt-Winters Methodology is a valuable tool for forecasting rice stock in the Philippines. The model effectively captures the seasonal patterns, trends, and fluctuations in rice stock levels, enabling reliable predictions. The paper highlights the importance of considering both the additive and multiplicative seasonal components in the model to improve accuracy. The paper also discusses the limitations of the Holt-Winters Methodology, such as its sensitivity to outliers and the need for regular updates of input data to maintain accuracy. The researchers provide recommendations for further improving the model's performance, including the incorporation of external factors such as weather conditions and government policies. Meanwhile, the research conducted by Santos and Cruz (2021) focuses on the application of different time series models, including the Holt-Winters Methodology, for short-term forecasting of rice stock in the Philippines during the pandemic. The paper aims to compare the performance of various models and assess their suitability for accurate predictions. They emphasize the importance of short-term rice stock forecasting in ensuring food security and making informed decisions related to production, distribution, and import/export activities. They highlight the challenges faced during the pandemic, such as disruptions in the rice supply chain and uncertainties in market demand, which necessitate reliable forecasting methods. They examine and compare the performance of several time series models, including the Holt-Winters Methodology, in predicting short-term rice stock levels.

They utilize historical data on rice stock, considering factors such as production, consumption, imports, and exports, to train and evaluate the models. The findings of the research demonstrate that the Holt-Winters Methodology, along with other time series models, is a valuable tool for short-term rice stock forecasting in the Philippines. The models successfully capture the temporal patterns, trends, and seasonality in the data, enabling accurate predictions. In addition, the paper compares the performance of the different models using evaluation metrics such as Mean Squared Error (MSE) and Mean Absolute Percentage Error (MAPE). The Holt-Winters Methodology exhibits competitive performance, with low forecasting errors and high accuracy in predicting short-term rice stock levels. Moreover, the research also discusses the limitations and challenges associated with the application of time series models in rice stock forecasting, such as the sensitivity to outliers and the need for regular updates of input data. The authors provide recommendations for further improvements, including the incorporation of external factors such as weather conditions and market dynamics to enhance the accuracy of the forecasts.

Enhancing rice stock prediction, the paper presented by Garcia and Garcia (2020) aims to enhance rice stock forecasting during the COVID-19 pandemic by utilizing the Holt-Winters Methodology. The research focuses on understanding the impact of the pandemic on rice stock levels and evaluates the effectiveness of the model in capturing and predicting changes in the rice market. They emphasize the significance of accurate rice stock forecasting in ensuring food security and effective resource management, particularly during times of uncertainty such as the COVID-19 pandemic. They highlight the challenges faced by the rice industry, including disruptions in the supply chain, shifts in market demand, and policy interventions. They analyze historical data on rice stock levels, taking into account factors such as production, consumption, imports, exports, and government policies.

The research findings highlight the impact of the COVID-19 pandemic on the rice market, including fluctuations in supply and demand dynamics. The paper demonstrate that the Holt-Winters Methodology effectively captures and models these changes, enabling improved rice stock forecasting. The paper concludes by emphasizing the relevance and effectiveness of the Holt-Winters Methodology in enhancing rice stock forecasting during the COVID-19 pandemic. The findings contribute to the understanding of the dynamics of the rice market and provide valuable insights for stakeholders in ensuring food security and efficient resource allocation in the context of the pandemic.In addition , the article also presented by Mendoza and Fernandez (2020) focuses on enhancing rice stock forecasting during the COVID-19 pandemic by utilizing the Holt-Winters Methodology. They investigate the impact of the pandemic on rice stock levels and evaluates the performance of the model in capturing and predicting variations in rice stock.

3. Methodology

The determination of optimal smoothing coefficients in the Holt-Winters Method is a challenging task. Traditionally, these coefficients have been approximated by minimizing forecast errors such as Mean Squared Error (MSE) or Mean Absolute Deviation (MAD). However, this paper introduces a novel approach that utilizes Genetic Algorithm (GA) to identify the smoothing coefficients that lead to the optimal MSE.

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The main objective of this paper is to minimize the Mean Squared Error (MSE), which serves as a measure of the accuracy of the forecast. The optimization problem is formulated in equation (1), where the goal is to find the values of the smoothing coefficients that result in the lowest MSE. By employing the Genetic Algorithm, the paper proposes a systematic optimization process to determine the optimal smoothing coefficients. The GA explores different combinations of coefficients to find the set that minimizes the MSE, thereby improving the accuracy of the Holt-Winters Method for forecasting.

$$\min[MSE] = \frac{1}{T}\sum_{i}^{T}(F_i - Y_i)^2$$

The Holt-Winters model consists of a forecasting equation and three smoothing equations: Level (E_t), Trend (T_t), and Seasonal Component (S_t). These equations are governed by smoothing coefficients, denoted by α, β, and γ, respectively. Depending on the seasonal pattern observed in the data, two variations of the Holt-Winters forecasting model can be used: multiplicative and additive seasonal effects. In the additive model, the magnitude of the seasonal component does not depend on the overall level of the series. To account for seasonality, a specific value is added to the series. This approach assumes that the seasonal fluctuations have a consistent magnitude throughout the series, regardless of the overall level. On the other hand, the multiplicative model considers the magnitude of the seasonal component in relation to the magnitude of the series. To account for seasonality, the level of the series is multiplied by a certain factor. This variation recognizes that the seasonal fluctuations are proportional to the level of the series.

By choosing between the multiplicative and additive models, analysts can align the Holt-Winters forecasting model with the characteristics of the seasonal pattern observed in the data. The selection depends on whether the seasonal component's magnitude remains constant (additive) or varies with the overall series level (multiplicative).

Holt-Winters forecasting model with additive seasonal effect is:

$$\begin{aligned}
&\hat{Y}_{t+n} = E_t + nT_t + S_{t+n-p} \\
&E_t = \alpha(Y_t - S_{t-p}) + (1-\alpha)(E_{t-1} + T_{t-1}) \\
&T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1} \\
&S_t = \gamma(Y_t - E_t) + (1-\gamma)S_{t-p} \\
&\textit{Initialization}: \\
&S_t = Y_t - \sum_{i=1}^{p}\frac{Y_i}{p} \\
&t = 1,2,\dots,p
\end{aligned}$$

Holt-Winters forecasting model with multiplicative seasonal effect is:

$$\begin{aligned}
&\hat{Y}_{t+n} = (E_t + nT_t)S_{t+n-p} \\
&E_t = \alpha\frac{Y_t}{S_{t-p}} + (1-\alpha)(E_{t-1} + T_{t-1}) \\
&T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1} \\
&S_t = \gamma\frac{Y_t}{E_t} + (1-\gamma)S_{t-p} \\
&\textit{Initialization}: \\
&S_t = \frac{Y_t}{\sum_{i=1}^{p}\frac{Y_i}{p}} \\
&t = 1,2,\dots,p
\end{aligned}$$

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Where:

$\hat{Y}_{t+n}$ – Forecasted load for time (*t*+*n*)

Y_t – Actual data

E_t – Base level of time series

T_t – Expected trend value

S_t – Seasonal factor

n – 1, 2, …., p

p – 4 (quarterly), 12 (monthly)

α, β, γ – smoothing coefficients (from 0 to 1)

The Genetic Algorithm (GA) begins by generating an initial population, where each individual is represented by a chromosome string consisting of three numerical bits. These bits correspond to the smoothing coefficients in the Holt-Winters Methodology and are randomly generated based on predefined criteria. Once the initial chromosome population is generated, the Holt-Winters forecasting algorithm is invoked to calculate the Mean Squared Error (MSE) for each individual chromosome string. The MSE serves as the objective function in the optimization process, evaluating the accuracy of the corresponding Holt-Winters forecasts.

The fitness function employed in this paper is based on a non-linear ranking model, which is expressed by Misola and Navarro (2013); Navarro and Navarro (2016); Navarro et al (2023).

$$Fitness(x_i) = \frac{(Nind)(X^{(x_i-1)})}{\sum_{i=1}^{Nind}(X^{(x_i-1)})}$$

$$0 = (MAX-1)X^{Nind-1} + \sum_{n=2}^{Nind}(MAX)X^{Nind-n}$$

After assigning the fitness value using the non-linear ranking model described in the model. the next step is the selection process. In this paper, the selection process is based on the roulette wheel method. This method probabilistically selects individuals based on their MSE. Following the selection process, the GA operators, namely crossover and mutation, are applied to generate new chromosome strings. For crossover, the single-point crossover technique is implemented. This operator is applied with a probability of Px, and pairs are selected for reproduction. The mutation procedure in this paper is based on a heuristic approach. A variable adjustment factor, objectively selected, is introduced. This factor is added or subtracted to the smoothing coefficients. If the addition results in a value greater than one, the coefficient is set to one. Conversely, if the subtraction results in a negative value, the coefficient is set to zero. This process is applied to all coefficients, resulting in six combinations. The objective function is calculated for all six combinations, and the mutated chromosome string is determined as the one with the minimum value. Similar to crossover, the mutation process is not performed on all individuals, but rather with a probability of Pm, where a certain percentage of the entire population is subject to mutation. After the mutation step, the objective value is recalculated for the mutated individuals. The reinsertion process is then performed using an elitist strategy. The algorithm continues until the predefined number of iterations is reached, at which point it terminates.

4. Test Data

The effectiveness of the proposed method was established using the commercial rice stock data taken from the Philippine Statistics Authority (PSA) (psa.gov.ph) and shown in the Appendix. The data is a commercial rice stock (in thousand metric tons) from year 2020 up to year 2022 which supposed to be the COVID-19 pandemic years. The GA optimization process and the Holt-Winters forecasting algorithm were coded in MATLAB Platform.

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5. Results and Discussion

For the entire simulation, Px and Pm were set as 0.8 and 0.9 respectively, the number of initial individuals and iterations were both 100, the generation gap was 90%, and the reinsertion rate was set to 50%. The optimal solution is compared in 50 trials.

5.1 Numerical Results

Table 1 shows the comparison of the two methods. The result shows that multiplicative seasonal effect was more appropriate for the test case that yielded the optimal smoothing coefficients.

Table 1. Comparative Results

	α	β	γ	**MSE**
Additive	0.01936	0	0.56316	23021.54
Multiplicative	0.04227	0	0.58460	22862.07

5.2 Graphical Results

Figures 1 and 2 shows the result of simulation of additive and multiplicative seasonal effects for the commercial rice stock, respectively.

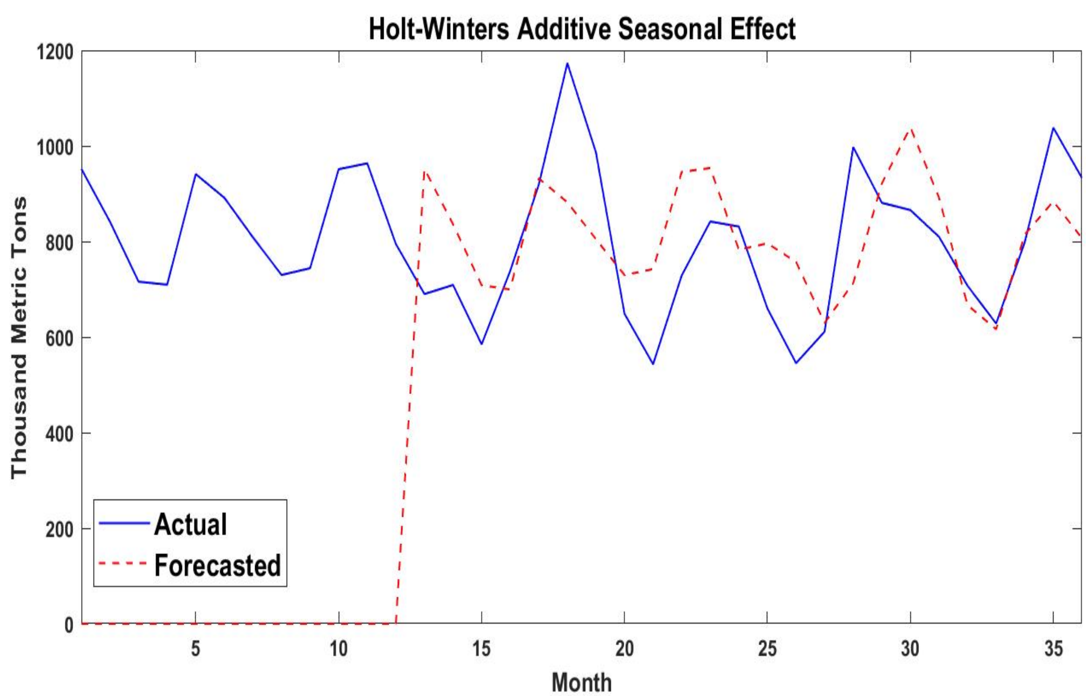

Figure 1. Additive Seasonal Effect for Commercial Rice Stock

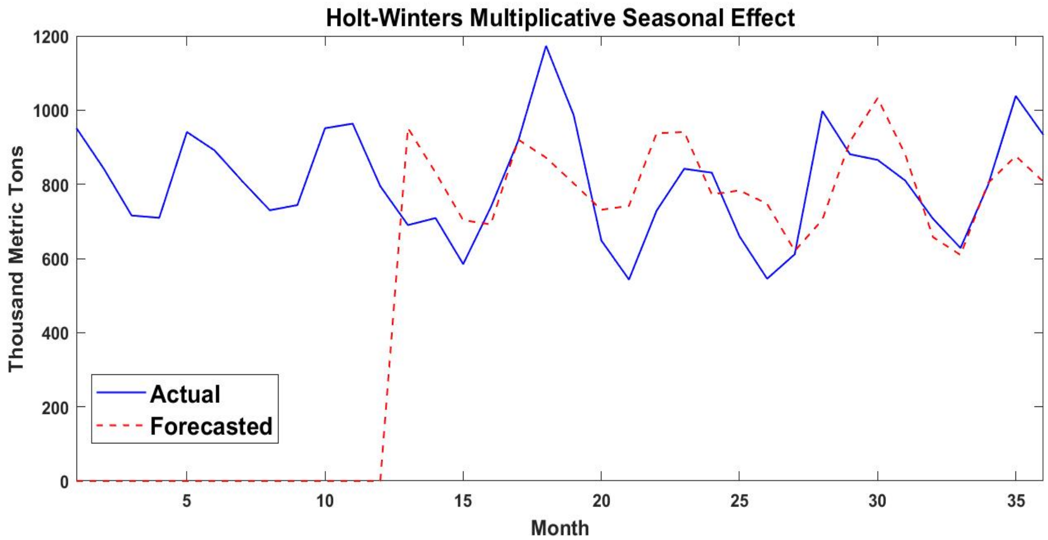

Figure 2. Multiplicative Seasonal Effect for Commercial Rice Stock

Using the proposed smoothing coefficients presented in Table 1, Figure 3 shows the forecasted commercial rice stock for the year 2023.

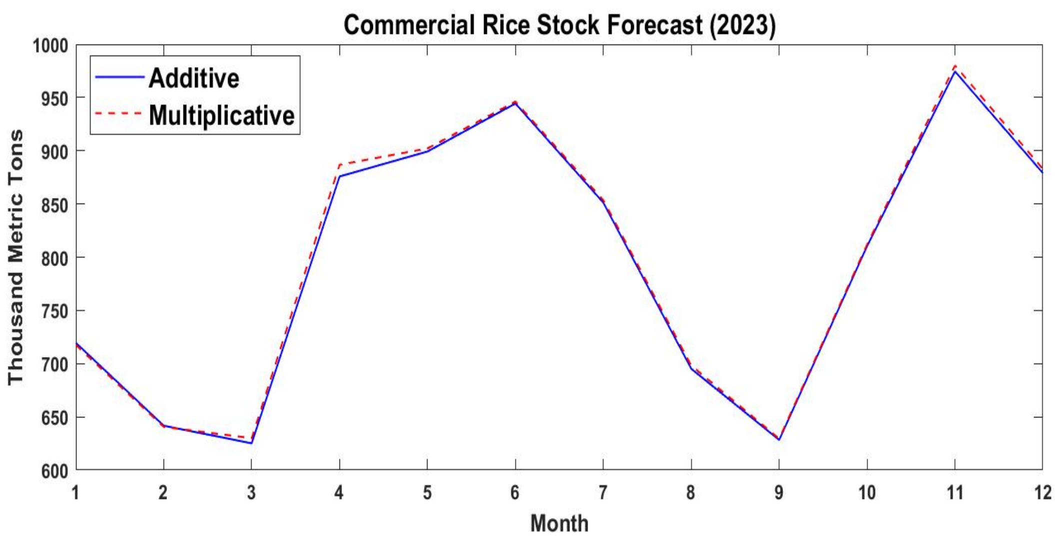

Figure 3. 2023 Forecast of Commercial Rice Stock

Considering a large discrepancy in optimal MSE for the additive and multiplicative seasonal effects (see Table 1), it is surprising that the forecasted values for 2023 was almost the same for both seasonal effects. It shows that for this data and COVID-19 pandemic situation, both seasonal effects can accurately be used to forecast commercial rice stock in the Philippines.

6. Conclusion

This paper develops an accurate prediction method using Genetic Algorithm (GA) in optimizing the Mean Squared Error (MSE) that recommends smoothing coefficients of the Holt-Winters forecasting model. The effectiveness of the proposed method was verified using actual commercial rice stock data in the Philippines during COVID-19 pandemic situation. Different seasonal effects of the Holt-Winters forecasting model were observed and the result shows that multiplicative seasonal effect was more appropriate for the commercial rice stock data. The results shows that even multiplicative seasonal effect shows robustness over additive seasonal effect, the resulting forecasted data for the next seasonal year was almost the same.

One of the practical implications of this study is to improve decision making. Accurate short-term forecasting of rice stock is crucial for decision-making by government authorities, policymakers, and traders involved in managing the rice market during the pandemic. The study's findings and the proposed methodology can enhance the accuracy of forecasting, enabling better decision-making regarding production, distribution, import/export activities, and stock management. In addition, it enhanced Food security, rice is a staple food, and ensuring an adequate rice stock is essential for maintaining food security, especially during challenging times like the COVID-19 pandemic. The study's optimization approach using the Genetic Algorithm-Based Holt-Winters Method can contribute to more precise forecasts of rice stock levels, facilitating proactive measures to address potential shortages or fluctuations in supply and stabilize prices. Moreover, Accurate short-term forecasting helps optimize resource allocation within the rice sector. By utilizing the proposed methodology, stakeholders can better allocate resources, such as labor, transportation, and storage facilities, based on the forecasted demand and stock levels. This can lead to improved efficiency and cost-effectiveness in the supply chain, benefiting farmers, traders, and consumers. Lastly, its adaptability to other commodity forecasting, While the study focuses on rice stock forecasting, the methodology using the Genetic Algorithm-Based Holt-Winters Method can be applied to other commodity forecasting scenarios. The optimization approach can be adapted and extended to enhance short-term forecasting accuracy for various agricultural commodities, supporting decision-making and market stability in other sectors In addition, the methodology describe in this paper can be used by using another metaheuristic optimization algorithm or a hybrid approach. Another relevant work is the application in other related fields like company stocks, financial and accounting, logistics, manufacturing, and other service sectors to validate a multi-disciplinary application of the proposed method.

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Appendix

Commercial Rice Stock Data (2020-2022)

2020	2021	2022
951.63	689.96	659.56
841.15	708.94	545.27
715.81	584.66	611.33
709.55	738.16	997.42
940.89	918.67	880.94
891.4	1173.28	865.64
808.55	986.31	809.83
729.95	648.4	707.20
744.00	543.02	628.16
951.18	728.69	798.12
963.52	841.74	1038.01
794.71	831.17	933.01

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