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Article

Analytical economic study of rice supply response in Egypt

Rehab A. H. Awad[1], Dina F. M. Enany[1], Amr S. S. El Sayed[1], Taher Kadah[2,*]

[1] Agricultural Economics Research Institute, Agricultural Research Center (ARC), Giza 12619, Egypt
[2] Central Laboratory of Residue analyses of Pesticides and Heavy Metals in Food (QCAP), Agricultural Research Center (ARC), Dokki, Giza 12311, Egypt
*** Corresponding author:** Taher Kadah, taherkadah166@hotmail.com

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Abstract: Recent studies have identified several challenges associated with rice production, which hinder the achievement of self-sufficiency in rice. As a crop that heavily relies on irrigation water, rice production has implications for the nation's water security. Nevertheless, there is still hope for reducing the future food gap by implementing agricultural policies that encourage farmers to increase production. Therefore, it has become essential to understand the responsiveness of rice cultivation area supply to changes, as this is crucial for making decisions regarding agricultural policies related to production and farm prices during the period from 2010 to 2023. The aim is to estimate farmers' responsiveness, and the time required to achieve this response, as well as the supply elasticity. To achieve the research objective, both descriptive and quantitative statistical analysis were used, applying the Stepwise method in its logarithmic form to estimate the Supply Response. The elasticity of supply response for the rice cultivation area was estimated to be approximately 1.86% in the short term and 2.09% in the long term. It was also found that the response time of the cultivated rice area supply in Egypt to changes is low, estimated at around 1.12. This may be due to the inability to expand the cultivated area of this crop in the following year, as rice cultivation requires large amounts of water, posing a challenge given the scarcity of water resources. Additionally, farmers aim to maximize profits from the crops they cultivate.

Keywords: supply response; R. solo model; correlation matrix; stepwise regression statistical flexibility

1. Introduction

Rice is one of the most important cereal crops in Egypt, holding a significant position in the Egyptian economy and food security. It is a key staple used to ease the consumption burden on wheat and bread. Egyptian rice holds a prominent place in global rice markets and exchanges, with Egypt being the fifteenth-largest producer globally, producing approximately 3.78 million tons, which accounts for about 0.7% of global production for the 2022/2023 season. Additionally [1], rice cultivation is geographically important, as it helps maintain soil fertility in certain governorates characterized by saline soil and low-lying terrain, such as the Fayoum Governorate. The Dakahlia and Kafr El Sheikh governorates are the highest producers of rice during the study period (2018–2022), accounting for approximately 28.52% and 23.16% of total production, respectively, followed by the Sharqia and Beheira governorates with about 18.53% and 14.85% of total national production on average during the study period [2].

Rice is also crucial to the Egyptian economy due to its role in the rice milling industry, which is one of the most important agricultural processing industries in Egypt. Furthermore, rice milling by-products are key components of concentrated animal feed.

The government has adopted an agricultural policy to reduce the area cultivated with rice due to its high-water consumption and the water challenges facing Egypt. This has led to a decrease in the cultivated area and, consequently, total production, resulting in a food gap and a shift from exporting to importing rice. This shift is driven by increased demand due to population growth and limited cultivated area, which has put additional pressure on Egypt's agricultural trade balance.

The research problem Recently, there have been challenges related to rice production that prevent achieving self-sufficiency. Given that rice is a water-intensive crop, it affects national water security. However, there is still hope for reducing the food gap in the future by adopting agricultural policies that encourage farmers to increase production.

The research aims is to estimate the degree of farmers' responsiveness to increasing the area cultivated with rice, the time required to achieve this response, and the elasticity of supply. This involves identifying the factors most influencing the cultivated area of rice, which is crucial for making decisions on agricultural policies related to production and farm prices for the period (2010–2023). This is achieved through the following:

1) Current Status and Economic Importance of Rice in Egypt during the Period (2010–2023):
    a) Development of key economic indicators related to rice production in Egypt (area, production, productivity).
    b) Development of key economic indicators related to rice consumption in Egypt (consumption, imports, exports, gap, per capita share, self-sufficiency).
2) Geographical Distribution of Major Rice Producing and Cultivating Governorates in Egypt.
3) Estimation of the Supply Response Function for Rice Cultivation Area during the Period (2010–2023).

2. Materials and methods

In this study, descriptive and statistical analysis methods were employed, and the Supply Response Model (Solo) was applied using the Stepwise Multiple Regression approach in both its linear and logarithmic forms. The objective was to identify and rank the most significant independent variables influencing the dependent variable, with a preference for the logarithmic form due to its effectiveness in estimation, especially when using lagged independent variables.

To estimate the Supply Response Function for the area planted with rice in Egypt during the current year, the cultivated area of rice in the current year was used as the dependent variable. Independent variables included per capita rice production for the current year (during the period 2010–2023), the farm gate price of rice with a two-year lag (2008–2021), as well as net returns for maize, water requirements for rice, net returns for rice, rice productivity, rice area, and the global price of rice, each with a one-year lag (2009–2022). A Correlation Matrix was constructed to examine multicollinearity issues between the variables under study. Additionally, measures were taken to ensure that random errors were not correlated with each other or with any of the independent variables (Autocorrelation) to verify the significant impact of these variables on the dependent variable (before proceeding to measure the response functions).

Finally, the Supply Response Function for rice, along with key competing crops such as maize and soybeans, was estimated. The study relied on both published and unpublished data from the Economic Affairs Sector of the Ministry of Agriculture and Land Reclamation, as well as data from the United States Department of Agriculture (USDA.gov).

3. Results and discussions

3.1. Current status and economic importance of rice in Egypt during the study period

Rice holds a distinguished position as one of the most important cereal crops in Egypt. The area cultivated with rice has represented about 47.5% of total summer cereal crops, and approximately 17.5% of total cereal crop area nationwide during the study period (2010–2023).

3.1.1. Development of the most important economic indicators related to rice production in Egypt during the period (2010–2023)

Cultivated Area: The data in **Table 1** indicate that the cultivated area in Egypt during the period (2010–2023) ranged between a minimum and maximum of approximately 1112 and 2100 thousand feddans in the years 2010 and 2016, respectively. By estimating the general time trend equation in **Table 2**, Equation (1), it was found that the area planted with rice in Egypt exhibited a general downward trend annually, which was statistically insignificant. This suggests that the rice cultivation area in Egypt fluctuated around its arithmetic mean, which was estimated at approximately 1633 thousand feddans during the study period.

Total Production: The data in **Table 1** indicate that the total production of rice in Egypt during the period (2010–2023) was characterized by fluctuations, ranging from a minimum of approximately 2800 thousand tons in 2018 to a maximum of about 4800 thousand tons in 2016. By estimating the general time trend equation for total rice production in Egypt, Equation (2) in **Table 2**, it was found that rice production followed a statistically significant general downward trend annually, with an estimated decrease of about 54.47 thousand tons per year, representing approximately 1.37% of the average production, which was estimated at 3985 thousand tons during the study period. The equation also shows that the R^2 value was estimated at 12%, indicating that 12% of the changes in total production were explained by the time factor, while the remaining changes were attributed to other factors.

Table 1. Economic indicators of rice crop in Egypt during the period (2010–2023).

Sunnah	Area (thousand acres)	Production (thousand tons)	Productivity (Ton/Acre)
2010	1112	3100	2.79
2011	1729	4250	2.46
2012	1902	4675	2.46

Table 1. (*Continued*).

Sunnah	Area (thousand acres)	Production (thousand tons)	Productivity (Ton/Acre)
2013	1902	4750	2.50
2014	1606	4530	2.82
2015	1606	4000	2.49
2016	2100	4800	2.29
2017	1882	4300	2.28
2018	1141	2800	2.45
2019	1877	4300	2.29
2020	1729	4000	2.31
2021	1235	2900	2.35
2022	1482	3600	2.43
2023	1556	3780	2.43

Source: Egypt rice area, yield and production (usda.gov) [2].

Table 2. General time trend of the most important economic indicators related to rice production in Egypt for the period (2010–2023).

Statement	Equation	*F*	R^2	Average	Rate of Change %
1. Area planted with rice (thousand acres)	Y = 21139.71 − 9.674 X (−0.46)	0.215	0.02	1633	0.59
2. Local production (thousand tons)	Y = 113828.50 − 54.47 X (−1.25) *	1.566*	0.12	3985	1.37
3. Acre productivity (Ton/Acre)	Y = 46.96 − 0.02 X (−2.28) *	5.21*	0.31	2.45	0.89

Source: calculated and collected from **Table 1**.

Yield per Feddan (tons/feddan): The data in **Table 1** indicate that the yield per feddan of rice in Egypt during the period (2010–2023) ranged between a minimum of approximately 2.28 tons per feddan in 2017 and a maximum of 2.79 tons per feddan in 2010. By estimating the general time trend equation for rice yield per feddan in Egypt, Equation (3) in **Table 2**, it was found that the yield followed a statistically significant general downward trend annually, with an estimated decrease of about 0.022 tons per feddan, equivalent to 0.89% of the average yield, which was estimated at 2.45 tons per feddan during the study period. The equation also indicates that the R^2 value suggests that approximately 31% of the changes in yield per feddan were explained by the time factor, while the remaining changes were attributed to other factors not included in the model.

3.1.2. The most important economic indicators related to rice consumption in Egypt (2010–2023)

Development of Rice Availability for Consumption in Egypt During the Period (2010–2023): The data in **Table 3** show the evolution of rice consumption in Egypt during the study period, indicating that it ranged from a minimum of approximately 3300 thousand tons in 2010 to a maximum of about 4300 thousand tons in the years 2016, 2019, and 2020. By estimating the general time trend equation for the rice available for consumption in Egypt, Equation (1) in **Table 4**, it was found that consumption followed a statistically significant upward trend annually, with an estimated increase of about 41.71 thousand tons, equivalent to 1.04% of the average consumption, which was estimated at 4023 thousand tons during the study period. This increase in consumption can be attributed to the continuous population growth in Egypt, which directly impacts consumption levels. The Equation (1) also indicates that the R^2 value suggests that approximately 40% of the changes in rice availability for consumption were explained by the time factor, while the remaining changes were attributed to other factors not included in the model.

Development of Rice Imports Quantity in Egypt During the Period (2010–2023): The data in **Table 3** show the development of rice imports in Egypt during the study period, indicating that they ranged from a minimum of approximately 15 thousand tons in 2012 to a maximum of about 806 thousand tons in 2018. By estimating the general time trend equation for rice imports in Egypt, Equation (2) in **Table 4**, it was found that imports followed a statistically significant upward trend annually, with an estimated increase of about 35.91 thousand tons, equivalent to 14.25% of the average rice imports, which was estimated at 252 thousand tons during the study period. This increase in rice imports may be attributed to the rising consumption levels. The equation also indicates that the R^2 value suggests that approximately 38% of the changes in rice imports were explained by the time factor, while the remaining changes were due to other factors not included in the model.

Development of Rice Exports Quantity in Egypt During the Period (2010–2023): The data in **Table 3** indicate that the quantity of rice exports from Egypt reached a maximum of approximately 700 thousand tons in 2012 and a minimum of about 5 thousand tons starting in 2020. By estimating the general time trend equation for rice exports in Egypt, Equation (3) in **Table 4**, it was found that exports followed a statistically significant downward trend annually, with an estimated decrease of about 46.68 thousand tons, equivalent to 23.69% of the average rice exports, which was estimated at 197 thousand tons during the study period. The equation also indicates that the R^2 value suggests that approximately 61% of the changes in rice export quantities were explained by the time factor, while the remaining changes were attributed to other factors not included in the model.

Table 3. Economic indicators related to consumption of rice crop in Egypt for the period (2010–2023).

Year	Consumption thousand tons	Imports Thousand Tons	Exports Thousand tons	Gap	Average per capita kg/ year	Self-sufficiency %
2010	3300	24	200	200	37.82	93.94
2011	3620	335	600	(630)	40.58	117.40
2012	4050	15	700	(625)	44.39	115.43
2013	4000	33	600	(750)	42.84	118.75
2014	4000	34	250	(530)	41.85	113.25
2015	3900	100	200	(100)	39.91	102.56
2016	4300	102	100	(500)	43.09	111.63
2017	4200	87	50	(100)	41.27	102.38
2018	4200	806	20	1400	40.49	66.67
2019	4300	303	20	0	40.71	100.00
2020	4300	232	5	300	40.01	93.02
2021	4050	609	5	1150	37.06	71.60
2022	4000	450	5	400	36.04	90.00
2023	4100	400	5	320	36.37	92.20

Source: Rice|USDA Foreign Agricultural Service [1].

Table 4. General time trend of the most important economic indicators related to consumption of rice crop in Egypt for the period (2010–2023).

Statement	Equation	*F*	R^2	Average	Rate of Change %
1. Consumption (thousand tons)	Y=−80094 + 41.71X (2.79) **	7.84*	0.40	4023	1.04
2. Imports (thousand tons)	Y=−72164.6 + 35.91X (2.68) *	7.21*	0.38	252	14.25
3. Exports (thousand tons)	Y=94330.02 − 46.68X (−4.27) *	18.25**	0.61	197	23.69
4. Gap (thousand tons)	Y=−193922 + 96.19X (2.71) *	7.32*	0.38	38	153.13
5. Average per capita (kg/year)	Y=750.47 − 0.352X (−2.45) *	5.99**	0.33	40.17	0.88
6. Self-sufficiency (%)	Y=4893.74 − 2.38X (−2.72) *	7.41*	0.39	99	2.40

Source: Calculated and collected from **Table 2** data. *Significance: *(10%), **(5%), ***(1%).

Development of the Rice Food Gap in Egypt During the Period (2010–2023): The data in **Table 3** indicate that the rice food gap in Egypt reached a minimum of approximately 750 thousand tons in 2013, while the gap reached its maximum at around 1500 thousand tons in 2018. By estimating the general time trend equation for the rice food gap in Egypt, Equation (4) in **Table 4**, it was found that the gap followed a statistically significant upward trend annually, with an estimated increase of about 96.19 thousand tons, equivalent to 153.13% of the average food gap, which was estimated at 38 thousand tons during the study period. This increase in the food gap may be attributed to rising consumption driven by population growth, combined with a decline in production, which could be linked to either a decrease or stagnation in the cultivated area. This stagnation is likely due to Egypt's ongoing water crisis, which has led to restrictions on the areas dedicated to rice cultivation, as it is a water-intensive crop. The equation also indicates that the R^2 value suggests that approximately 38% of the changes in the gap between rice consumption and production were explained by the time factor, while the remaining changes were due to other factors not included in the model.

Development of the Per Capita Rice Consumption in Egypt for the Period (2010–2023): The data in **Table 3** indicate that the average per capita consumption of rice in Egypt reached a minimum of about 36.04 kg/year in 2022, while the maximum was approximately 44.39 kg/year in 2012. By estimating the general time trend equation for per capita rice consumption in Egypt, Equation (5) in **Table 4**, it was found that it followed a statistically significant downward trend annually, with an estimated decrease of 0.352 kg/year, equivalent to 0.88% of the average per capita consumption, which was estimated at 40.17 kg/year during the study period. This decline may be attributed to the increasing population and, consequently, the rising consumption of rice throughout the study period. The equation also indicates that the R^2 value suggests that approximately 33% of the changes in per capita rice consumption were explained by the time factor, while the remaining changes were due to other factors not included in the model.

Development of Rice Self-Sufficiency in Egypt During the Period (2010–2023): The data in **Table 3** indicate that Egypt's self-sufficiency rate in rice reached its minimum at 66.67% in 2018, while its maximum was 118.75% in 2013. By estimating the general time trend equation for rice self-sufficiency in Egypt, Equation (5) in **Table 4**, it was found that the self-sufficiency rate followed a statistically significant downward trend annually, with an estimated decrease of 2.38%. The average self-sufficiency rate during the study period was estimated at 99%. The decline in self-sufficiency rates can be attributed to the growing gap caused by increased consumption due to population growth and the decline or stagnation in rice production. This decrease in production may be due to reductions in the area of cultivated land allocated for rice or its stagnation, largely influenced by Egypt's water crisis and subsequent limitations on the cultivation of water-intensive crops like rice. The equation also indicates that the R^2 value suggests that approximately 39% of the changes in rice self-sufficiency are explained by the time factor, while the remaining changes are due to other factors not included in the model.

3.2. Geographic distribution of rice cultivation and production in major producing governorates for the average period (2018–2022)

The geographic distribution of rice cultivation across governorates shows significant regional differences in both area and production. This variation is due to soil suitability and favourable climatic conditions for rice cultivation, which are influenced by soil salinity and water availability, as rice is a high-water-demand crop.

Table 5 highlights the relative importance of major rice-producing governorates in terms of area and production for the average study period (2018–2022). The governorate of Dakahlia ranks first in both area and production, with approximately 307.03 thousand acres and 1192.33 thousand tons, representing about 27.39% and 28.52% of the total national average for rice area and production, respectively. Kafr El Sheikh ranks second with about 241.69 thousand acres and 968.14 thousand tons, representing approximately 21.56% and 23.16%, respectively. The governorate of Sharqia ranks third with approximately 227.89 thousand acres and 774.91 thousand tons, representing about 20.33% and 18.53%. The governorate of Beheira ranks fourth with approximately 170.16 thousand acres and 620.75 thousand tons, representing about 15.18% and 14.85%. Lastly, the governorate of Gharbia ranks fifth with approximately 82.64 thousand acres and 305.40 thousand tons, representing about 7.37% and 7.30% of the total national average for rice cultivation and production during the study period.

It is worth noting the efforts of the state in agricultural water security policies, which focus on preserving the limited water resources in Egypt without compromising the food security of rice, a key and strategic crop in the country. The state has prioritized the cultivation of rice varieties with short growth periods that can tolerate soil salinity and require low water input, aiming to reduce water consumption while ensuring high productivity. Additionally, the government has implemented some regulatory restrictions, including fines and prohibitions on rice cultivation outside the designated areas. This is stipulated in Law No. 147 of 2021, which imposes penalties and fines for cultivating rice in areas not approved for its production.

Table 5. Relative importance of rice production and cultivation governorates in Egypt for the period (2018–2022).

Governorate	Average Area (P)	Average production (tons)	Area % of total	Production % of total
Dakahlia	307,027	1,192,331	27.39	28.52
Kafr El-Sheikh	241,698	968,139	21.56	23.16
Eastern Province	227,893	774,914	20.33	18.53
Lake	170,164	620,750	15.18	14.85
Gharbia	82,642	305,401	7.37	7.30
Damietta	47,942	169,358	4.28	4.05
Port	26,636	91,457	2.38	2.19
Ismailia	5359	18,320	0.48	0.44
Qalyubia	3711	11,550	0.33	0.28
Alexandria	2848	10,373	0.25	0.25
Al-Fayyoum	2701	9116	0.24	0.22
Beni Suef	1249	5032	0.11	0.12
New Valley	821	2967	0.07	0.07
Nubaria	301	990	0.03	0.02
Suez	84	218	0.01	0.01
Menufia	12	42	0.00	0.00
Assiut	3	12	0.00	0.00
Total	1,121,093	4,180,968	100	100

Source: Egypt rice area, yield and production (usda.gov) [2].

Estimating the Supply Response Function for Rice Area during the Period (2010–2023): Given the diversity of concepts and methods used to study the supply response of agricultural crops, each approach depends on the type of estimates desired and the specific objectives of the study. Supply response studies for agricultural crops are fundamental for agricultural policymakers and decision-makers when planning for the agricultural sector, particularly when formulating agricultural development plans. Therefore, several distributed lag models have been employed in analyzing supply response, such as the Fisher model, the Koyck model, the Almon model, the adjusted Nerlove model, the Solow model, the Jorgenson model, and the Kidiye model. Below is a brief overview of the most important of these models:

Fisher Model: This model assumes that the effect of an independent variable on a dependent variable is not fully realized in the current period but is distributed over several time periods. In other words, the effects of independent variables are strong in the current period and then decrease in an arithmetic sequence (t) over time until they approach zero [3]. The model is formulated as:

$$A_{it} = \alpha + B_1P_{it} + B_2P_{i(t-1)} + B3P_{i(t-2)} + \ldots + BnP_{i(t-n-1)} + U_t$$

The model can also be simplified by aggregating different price periods into a single independent variable:

$$A_{it} = \hat{\alpha} + \hat{B}\ P_{itm} + U_t$$

M. Nerlove Model: Nerlove developed the partial adjustment model based on the Koyck model, assuming that the planted area is affected not only by the previous year's price but also by the planted area in the previous year [4,5]. The model is:

$$A_{it} = \alpha\lambda + B\lambda\, P_{i\,(t-1)} + (1-\lambda)\, A_{i\,(t-1)} + \lambda\, U_t$$

The estimated model is:

$$A_{it} = \hat{B}_0 + \hat{B}_1\, P_{i\,(t-1)} + \hat{B}_2\, A_{i\,(t-1)} + U \times_t$$

where:

$$\alpha = \hat{B}_0/\lambda,\ \beta = B_1/\lambda,\ \lambda = 1 - \hat{B}_2,\ \lambda\, Ut = U \times_t$$

where: (λ): annual response coefficient, ($1/\lambda$): response period, B $\lambda(\overline{P/A})$: price elasticity in the short term, and long-term price elasticity B $(\overline{P/A})$.

R. Solo Model:

Robert Solo proposed an infinite lag distribution model, where independent variables are infinite. Using Pascal's distribution and combinatorial laws [6], Solo derived the following model:

$$Ait = \alpha\,(1-\lambda)^2 + B\,(1-\lambda)^2\, Pi\,(t-1) + 2\lambda\, A_{i\,(t-1)} - \lambda_2\, A_{i\,(t-2)} + [U_t - 2\lambda U_{t-1} + \lambda_2\, U_{t-2}]$$

The estimated model is:

$$Ait = \hat{B}_0 + \hat{B}1\, P_{i\,(t-1)} + \hat{B}_2\, A_{i\,(t-1)} - \hat{B}_3\, A_{i\,(t-2)} + U \times_t$$

where: The response period is $[1/(1-\hat{B}_2 - B_3)]$ and the short-term elasticity is $[B1 \times (\overline{Pt} - 1/\bar{A})]$, while the long-term elasticity is outside the division of short-term elasticity by $(1 - \hat{B}_2 - \hat{B}_3)$.

3.3. Results of statistical estimation of supply response functions

Estimating the economic function of the supply response of rice-planted areas is of paramount importance in the field of production economics in general, and agricultural production in particular [7,8]. The results of such estimates can be utilized in the formulation of national development plans, as they aim to identify the key variables affecting the area planted with rice during the period (2010–2023).

Additionally, this estimation allows for the identification of the most significant economic variables influencing the expansion of the planted area for this important strategic crop. To estimate this function, it is essential to have a suitable time series of data related to the variables involved. By applying the logarithmic transformation to the previous model [9], the following linear logarithmic function was obtained:

$$\text{Log } Y_i = \log a + b1 \log N_{1t} + b2 \log N_{2t-1} + b3 \log A_{it-1} + b_4 \log Y_{it-1} + b5 \log N_{3t-1} + b_6 \log W_{t-1} + b7 \log P_{t-2} + b_8 \log C_{t-1}$$

where: * Significant at 0.1, ** Significant at 0.05, *** Significant at 0.01

1) A_{it}: The estimated value of the area planted with the crop (one thousand acres) in the current year (as a dependent variable).
2) N_{1t}: Net yield of soybean crop (EG/ton) at a slower period of the previous year.
3) N_{2t-1}: Net yield of rice crop (EGP/ton) in a period of Delay of one year of the previous Stepyear.
4) A_{it-1}: Rice area (thousand acres) In a period of slower than a year before.
5) Y_{it-1}: Rice productivity (ton/acre) in a slower period of the previous year.
6) N_{3t-1}: Net yield of corn (le Egypt/ton) in a slower period of the previous year.

7) W_{t-1}: Rice water rationing (m3/acre) with a period of slowing down the previous year.
8) P_{t-2}: The farm price of rice (le Egypt/ton) in two slower periods for the previous two years.
9) C_{t-1}: Production per capita (kg/capita) for the current year.

To estimate the supply response functions, several distributed lag models were utilized [10–12]. The supply response relationship for the crops under study was estimated using both linear and logarithmic models. Several attempts were made to select the model that aligns with both statistical and economic logic. Subsequently, a Correlation Matrix was estimated between the dependent variable and the independent variables, which are presumed to affect the dependent variable. This was done to ensure that no multicollinearity exists among the variables under study. Then, the Stepwise Regression model was employed in both its linear and logarithmic forms. Variables that had signs inconsistent with economic logic were excluded, and the most appropriate model form was selected. Through this process, one or more variables were eliminated from the model for the period (2010–2023) to assess their impact on the estimation of the supply response function for rice in Egypt, the elasticity of the remaining variables in the model, and their statistical significance.

Additionally, standard statistical tests were conducted to evaluate the accuracy and efficiency of the estimates, such as the F-test, T-test, coefficient of determination (R^2), and the adjusted coefficient of determination (R^2-adjusted), as outlined below:

$$A_{it} = 1.219 - 0.214\ N1t + 0.254\ N2_{t-1} - 0.109\ A_{it-1} + 0.286\ Y_{it-1} - 0.446\ N3_{t-1} - 0.393\ W_{t-1} + 1.285\ P_{t-2} + 1.320\ C_{t-1}\ (-1.488)\ {*}\ (1.880)\ {*}\ (-1.080)\ (1.254)\ (-2.456)\ {**}\ (-2.384)\ {**}\ (4.142)\ {***}\ (11.257)\ {***}$$

$$R^2 = 0.95\ R^{-2} = 0.92\ F = 31.39\ N = 14$$

*Significance: *(10%), **(5%), ***(1%).

The results of the statistical estimation indicate that the most compatible model for the supply response of rice in absolute terms is the Solow model in its logarithmic form, which has shown significance with respect to several variables: the current per capita production for the period (2010–2023), as well as the previous year's variables (rice area, net return of corn, rice productivity, water quota for rice, net return of rice, and net return of soybeans) for the period (2009–2022). Additionally, the model has been significant with the farm price of rice from two years prior, covering the period (2008–2021). These factors align with economic logic and are critical in influencing the current planted area of rice for the period (2010–2023). The coefficient of determination (R^2) was approximately 0.95, suggesting that about 95% of the changes in the area planted with rice in the current year can be attributed to variations in these aforementioned variables. Rasha confirmed that the elasticity of the response of the area planted with rice to changes in its price was around 0.285. This means that a 10% increase in the price of rice would lead to a 2.8% increase in the area planted in the short term and approximately a 6.4% increase in the long term, Upon reviewing the elasticities, it was found that all of them were less than one, which indicates that the supply of the rice crop is described as inelastic. [13].

The previous model reveals that the elasticity of the response of the rice area to changes in the net return of soybean from the previous year is negative, with a value of approximately (0.214). This elasticity is statistically significant at the 0.1 level, indicating that a 10% decrease in the net return of soybeans in the previous year could increase the area planted with rice by about 2.14% in the following year.

Additionally, a statistically significant positive relationship was found for the elasticity of the response of the rice area to changes in the net return of rice in the previous year, which was approximately (0.254) at the 0.1 level. This indicates that a 10% increase in the net return of rice in the previous year could lead to an increase of about 2.54% in the area planted with rice in the following year. Moreover, the statistical significance of both the area and productivity of rice from the previous year in affecting the current rice area response was not established. Despite this, a negative relationship was observed between the current area of rice and the area of rice from the previous year, suggesting that these variables are stable and fluctuate around their averages.

This indicates a reduced responsiveness of the rice supply to these variables, attributed to the limited potential for expanding the area planted with rice due to the government's regulations on the area to be cultivated. This limitation arises from the high water quota required for rice, as well as the reluctance of some farmers to plant rice for consecutive years due to its depleting effect on soil and significant water consumption during the growing season.

In contrast, the previous year's rice productivity positively correlates with the current planted area of rice, as increased productivity encourages farmers to cultivate rice the following year to take advantage of the higher yields and maximize their net returns from this strategic crop.

Furthermore, the elasticity of the current area of rice planted in Egypt in response to changes in the net return of corn from the previous year, as well as the water quota for rice from the previous year, was estimated to be negative at approximately (0.446) and (0.393), respectively, during the period (2009–2022). This implies that a 1% decrease in these variables in the previous year could result in an increase of about 4.46% and 3.93% in the area planted with rice in Egypt in the following year, respectively. The previous model also confirms the statistical significance of the elasticities of these variables at the 0.05 significance level.

Additionally, the elasticity of the current area of rice planted in Egypt in response to changes in the farm price of rice from two years prior, as well as the per capita production of rice for the current year, was positively estimated at approximately (1.258) and (1.320), respectively. This indicates that a 1% increase in these variables could raise the area planted with rice in the current year in Egypt by about 12.85% and 13.20%, respectively. The previous model also confirms the statistical significance of these elasticities at the 0.01 significance level.

The previous model illustrates the varying degrees of responsiveness of the studied variables on the area planted with rice in Egypt for the current year, indicating the different relative importance of these variables. It was found that the per capita local production of rice is the most significant factor influencing the area planted with rice in Egypt during the study period (2010–2023), followed by the net return of corn (with a lag), the water quota for rice (with a lag), the net return of rice (with a lag), the net return of soybeans (with a lag), and the farm price of rice (with two lags) concerning the current area of rice.

The short-term supply response elasticity of the area planted with rice was estimated at approximately 1.86%, indicating that a one-pound increase in the farm price per ton would lead to an 18.6% increase in the area planted with rice. In contrast, the long-term supply response elasticity was estimated at approximately 2.09, indicating that a one-pound increase in the farm price per ton would result in a 20.9% increase in the area planted with rice [14–16].

It was also found that the response period of the area planted with rice in Egypt to changes is low, estimated at around 1.12. This could be attributed to the inability to expand the area cultivated with this crop in the following year, as rice cultivation requires significant amounts of water, which poses a challenge given the scarcity of water resources. Therefore, the area planted with rice is determined to maintain the sustainability of the water supply.

Additionally, farmers aim to maximize their profits from the crops they cultivate. While rice cultivation can be profitable, it is also costly, which may reduce overall profitability. Consequently, farmers may opt to grow alternative crops that offer similar or higher returns, such as corn and soybeans, to maximize the benefits from their cultivated area [17,18].

4. Conclusion

The study results indicate a variation in the elasticity of the response of the studied variables on the area planted with rice in Egypt for the current year. This highlights the relative importance of these variables. It was found that the per capita share of domestic rice production is the most significant factor affecting the rice cultivated area in Egypt during the study period (2010–2023). Following this, the net return of maize (with a lag period), the water allocation for rice (with a lag period), the net return of rice (with a lag period), the net return of soybeans (with a lag period), and the farm price of rice (with a two-period lag) sequentially influence the rice cultivation area in Egypt for the current year. This shows that increasing the net return of maize could reduce the rice cultivation area, necessitating efforts to reduce production costs for rice and increase government support for producers.

The results indicated that a 10% decrease in the net return of soybeans in the previous year could increase the rice cultivation area by approximately 2.14% in the following year. Similarly, a 10% increase in the net return of rice in the previous year could increase the rice cultivation area by approximately 2.54% in the following year. Mekawy confirmed an inverse relationship between total per-acre costs and the net return per acre at current prices, and the regression coefficients indicated that a decrease in total costs by one pound would lead to an increase in the net return per acre by approximately 1256 pounds [19]. This is because farmers would tend to cultivate crops that increase their income.

The study results showed that the per capita share of domestic rice production is one of the most important factors affecting the rice cultivation area in Egypt. This is consistent with Mekawy's findings in his study, where he estimated the price elasticity of demand for rice using the logarithmic function, finding that a 1% decrease in the consumer price leads to an increase in the quantity of rice consumed by approximately 0.032% [19].

The short-term supply elasticity of the rice cultivation area was estimated at around 1.86%, indicating that an increase in the farm price by one pound per ton would lead to an increase in the rice cultivation area by approximately 1.86 thousand feddans. In the long term, the supply elasticity was estimated at around 2.09, suggesting that an increase in the farm price by one pound per ton would lead to an increase in the rice cultivation area by approximately 2.09 thousand feddans. This result aligns with Rasha's findings, which indicated that the elasticity of the rice cultivation area response to price changes was around 0.285. This means that a 10% increase in the price of rice leads to a 2.8% increase in the cultivated area in the short term and approximately 6.4% in the long term [13]. Given the water scarcity and the enactment of regulations to reduce the rice cultivation area, the government imported quantities of rice to compensate for the quantities previously produced. Additionally, they directed the cultivation of higher-yield, drought-tolerant varieties.

The study results revealed that increased productivity is an encouraging factor for farmers to cultivate rice in the following year, benefiting from higher productivity and achieving the highest net return from cultivating this important strategic crop. This means that the previous year's rice productivity variable positively correlates with the current rice cultivation area. However, it is impossible to expand the rice cultivation area due to the state's determination of the area that should be planted with rice, given the high water allocation for this crop.

The study confirmed that farmers aim to maximize profits from the crops they cultivate. While rice cultivation may be profitable, it is costly, reducing profitability and prompting a shift towards cultivating crops with similar or higher returns, such as maize and soybeans, to achieve maximum benefit from the cultivated area.

5. Recommendations

In light of the study's results, the following recommendations are proposed:

Encouraging the cultivation of new rice varieties, particularly early-maturing, high-yield varieties and drought-resistant varieties with low water requirements, aligns with the state's water security policies. Additionally, developing varieties that can withstand climate changes such as heat and humidity should be promoted by offering incentives to farmers for cultivating these varieties.

Increasing the presence of demonstration fields to showcase the productivity of the new early-maturing, high-yield, and drought-resistant varieties to encourage farmers to cultivate them in Egypt's designated rice-growing areas, according to the permitted and specified land area.

Evaluating legislative policies related to the illegal cultivation of rice to account for the country's limited water resources, enhancing oversight, and enforcing the law on violators.

Encouraging farmers to plant other summer crops, such as maize and soybeans, by providing information and guidance on the farm prices of rice and its competing crops, along with offering production inputs at reasonable prices to reduce production costs. The optimal crop composition for rice-growing areas should also be disseminated before the next agricultural season to enable farmers to make informed decisions on planting the most profitable crops.

Expanding programs aimed at reducing post-harvest losses of this crop throughout the stages of production to consumption, considering the limited water and rice-growing land area available.

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