

Determinants of Rice Production, a Food-Dependent Crop in Mexico (*Oryza sativa*)

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ABSTRACT

Objective: To identify the economic factors that impact national rice production from 2003 to 2022, and to assess the production stage of each factor.

Design/methodology/approach: The methodology involves calculating growth rates for the relevant variables and estimating a multiple linear econometric model. The determinants of the production model are the planted area, the economically active population in the agricultural sector, and the total use of nitrogen fertilizers.

Results: The estimators indicate a positive relationship between production and planted area ($\hat{\beta}_1 = 0.825$); a positive relationship between the economically active population in the agricultural sector ($\hat{\beta}_2 = 1.276$); and a positive relationship with nitrogen ($\hat{\beta}_3 = 0.458$). The findings support the theoretical expectations. The results indicate increasing marginal returns for the economically active population agriculture, which has the greatest impact on production, while planted area and nitrogen indicate decreasing marginal returns.

Findings/conclusions: In general, the sum of the elasticities indicates increasing returns to scale (2.559). This finding helps in designing strategies focused on the main production factors recognizing real limitations.

Keywords: *Oryza sativa*, econometric model, production function, production factor, elasticity.

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INTRODUCTION

In Mexico, self-sufficiency in rice production was achieved in 1988. In subsequent years, however, the rice sector underwent a structural transformation characterized by limited production incentives (Economics Commission, 2022, p. 6). Trade liberalization and a process of accelerated modernization profoundly reshaped Mexico's agricultural production and commercial activities. The trade agreement facilitated the reallocation of cultivated land and improved yields across several crops (González, 2001). Rice, wheat, yellow maize, and beans experienced a decline in production due to insufficient international competitiveness. Policy priorities shifted toward the cultivation of forage crops, legumes, fruits, and vegetables (Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food - SAGARPA, 2017, p. 2). Consequently, staple grains progressively lost strategic prominence, ultimately positioning the country as a net importer. According to Article 179 of the Sustainable Rural Development Law (SRDL), rice is classified as a strategic crop

and fulfills the objective of planning and organizing agricultural production to guarantee food security (Sustainable Rural Development Law, 2021, p. 53). According to Reyes *et al.* (2024), *per capita* rice consumption amounts to 8.5 kilograms. The magnitude of domestic insufficiency is evident: in 2016, national rice production satisfied only 21.62% of total domestic consumption. Consequently, 929,482 tons were imported to meet internal demand, primarily from the United States, Brazil, and Uruguay (SAGARPA, 2017, p. 2). By 2021, rice imports had reached 1,018,000 tons, accounting for 90% of domestic demand (Economics Commission, 2022, p. 6), thereby exacerbating dependence on the external sector. Enhancing domestic rice production would reduce vulnerability to international market volatility and mitigate adverse effects arising from price surges or food crises that could disrupt the regular flow of imports (Puyana & Romero, 2004, p. 108). In Mexico, imports originate predominantly from the United States, a country that holds a geographical advantage in transportation costs relative to other exporters. At the national level, the principal rice-producing states are Campeche, Nayarit, Tamaulipas, Michoacán, Veracruz, Colima, and Morelos. The cultivated area in Mexico totaled 40,841 hectares, generating a production volume of 257,000 tons (Agrifood and Fisheries Information Service - SIAP, 2022).

The literature on rice studies encompasses diverse market analyses, particularly those estimating supply, demand, and local competitiveness dynamics. However, empirical analyses of national crop production and its relationship with production factors remain underdeveloped and relatively scarce. This issue can be addressed through the Cobb-Douglas model, which enables a parsimonious yet robust representation of the relationship between inputs and output under supporting assumptions, including exogenous total factor productivity and factor substitutability. By employing a generalized abstraction of rice production through an econometric model, it is possible to estimate the elasticity of each production factor. The study posits a direct relationship between cultivated area and rice output, assuming technical efficiency and abstracting from climatic considerations. Likewise, a positive relationship between labor and rice production is hypothesized, based on the inferred existence of labor surplus derived from latent population within the primary sector capable of expanding production, as documented by Pérez *et al.* (2019). Rice is a crop with high demand for urea (nitrogen-based fertilizer); therefore, a direct relationship with rice production is anticipated, consistent with studies on fertilizer optimization. Within a context of pronounced trade dependence and limited domestic output, identifying the relationship between national rice production and production inputs will enable the quantification of both the direction and magnitude of their effects. The aim of this study is to estimate the elasticities of productive inputs with respect to national rice output. Such estimates may inform the design of strategic policies aligned with the efficient use of production factors, thereby fostering increased output and mitigating external dependence, while recognizing production factors as essential instruments of agricultural development.

MATERIALS AND METHODS

This research adopts a quantitative, empirical, and econometric approach. The estimation of a growth rate constitutes a fundamental indicator for assessing the evolution

of a variable over a specified period. The growth rate for the period is expressed as follows:

$$Tc_p = \left(\left(\frac{VF}{VI} \right) - 1 \right) \times 100 \quad (1) \text{ and the average annual growth rate is; } Tc_{pa} = n \sqrt[n]{\left(\left(\frac{VF}{VI} \right) - 1 \right)}$$

(2). The calculation is performed to identify the temporal dynamics of an economic variable.

To analyze production dynamics, the methodology employed by Pérez *et al.* (2019) is adopted, specifically the estimation of a Cobb-Douglas production function, which is widely applicable at both the microeconomic and macroeconomic levels and enables the assessment of the impact of production inputs land, labor, and capital (Mejía *et al.*, 2023). At the microeconomic level, the Cobb-Douglas function approximates the technological behavior of productive units, whereas at the macroeconomic level it serves as an aggregated representation of the production process. This abstraction provides analytical simplicity and facilitates the direct interpretation of parameters. Its application rests on restrictive assumptions, including perfect competition, well-defined factor markets, and stable (exogenous) technology over time. Moreover, it assumes a constant elasticity of substitution equal to one among factors, attributing changes in output exclusively to variations in productive inputs rather than to shifts in the production function itself (Gujarati, 2010). In the present analysis, the model is justified as an empirical approximation under the principle of parsimony, explicitly acknowledging its theoretical and econometric limitations. Its economic interpretation, statistical properties, and theoretical coherence link production theory through a Cobb-Douglas-type production function. Through an adaptation of the methodology applied by Pérez *et al.* (2018) and Guzmán *et al.* (2019), a log-log econometric model is proposed and estimated using the Ordinary Least Squares (OLS) method. The estimated parameters of the variables influencing rice production represent the output elasticities of the production factors.

The model was estimated using the RStudio statistical package. The selected variables are theoretically relevant and recurrently employed in agricultural literature as proxies for land, labor, and capital inputs. The availability of official statistical information disaggregated by production factor and crop at an aggregated level is limited; therefore, proxy variables are employed to operationally approximate these theoretical constructs. Consequently, the estimated coefficients should be interpreted as approximate associations rather than exact structural effects, a limitation explicitly acknowledged in the analysis. Data on rice production and harvested area were collected from the Agrifood and Fisheries Information and Consultation System (SIACON). The economically active population in the agricultural sector was obtained from the National Institute of Statistics and Geography (INEGI), and total nitrogen fertilizer use was sourced from the Food and Agriculture Organization of the United Nations Statistical Database (FAOSTAT). The study covers the period 2003-2022 with annual frequency.

Y: Rice production, measuring the total quantity of output obtained during the calendar year. Unit of measurement: metric tons (t).

SSE: Harvested rice area, defined as the land area sown with rice during a calendar year. Unit of measurement: hectares (ha).

PEAa: Economically active population in the agricultural sector, defined as the number of individuals engaged in the sector during the specified year. Unit of measurement: number of persons. This variable serves as a proxy for labor input in the study. The approximation is based on the assumption that, at an aggregated level, fluctuations in the agricultural economically active population reflect changes in the relative availability of labor within the sector's productive activities. The limitations associated with this factor are acknowledged; results should be interpreted as an aggregate approximation rather than as a direct measure of the specific labor input used in rice production.

N: Nitrogen use or fertilizer use by nutrient, measured as nitrogen fertilizer applied per unit of cultivated land. Unit of measurement: kilograms per hectare (kg/ha). Given the difficulty of quantifying crop-specific local fertilizer use to construct a consistent time series, total national nitrogen use is employed as a proxy variable, under the assumption that its temporal evolution reflects changes in the average fertilization intensity of the agricultural sector. Results associated with this variable should therefore be interpreted as a general approximation rather than as a direct measure of effective fertilizer use in rice cultivation.

Rice production is modeled as a function of harvested rice area, the economically active population in the agricultural sector as a proxy for labor potential, and total nitrogen fertilizer use within the sector:

$$\ln(\hat{Y}_i) = \hat{\beta}_0 + \hat{\beta}_1 \ln(SSe_i) + \hat{\beta}_2 \ln(PEAa_i) + \hat{\beta}_3 \ln(N_i) + \hat{\varepsilon}_i \quad (3)$$

where: \hat{Y}_i represents rice production; $\hat{\beta}_i$ denotes the estimated parameters; SSe_i is harvested rice area; $PEAa_i$ is the economically active population in the agricultural sector; N is nitrogen fertilizer use; and $\hat{\varepsilon}_i$ is the stochastic error term.

The corresponding Cobb-Douglas production function is specified as:

$$Y_i = \beta_0 SSE_i^{\beta_1} PEAa_i^{\beta_2} N_i^{\beta_3} \quad (4)$$

According to agricultural production theory, the following relationships are expected:

- Rice production exhibits a direct relationship with harvested rice area.
- Rice production exhibits a direct relationship with the dynamics of the economically active population in the agricultural sector.
- Rice production exhibits a direct relationship with nitrogen fertilizer use.

Potential endogeneity may arise between Y and SSe, as changes in output can influence decisions regarding cultivated area through expectations of yields, prices, climatic conditions, or direct production support policies. The inclusion of harvested area as an explanatory variable may also introduce a conceptual multicollinearity concern. Therefore, results must be interpreted cautiously, recognizing that the estimated relationship reflects structural dependence rather than an identifiable causal effect.

Given that the analysis is based on a time series comprising 20 observations, the identification of long-run patterns is subject to statistical limitations. Visual inspection is useful as an exploratory tool, yet insufficient to formally establish the stochastic properties of the series. Consequently, unit root tests are applied to assess stationarity in small samples. Due to sample size constraints, the Generalized Least Squares Dickey-Fuller (DF-GLS) test is employed, as it has been proposed as a more efficient alternative to the conventional Augmented Dickey-Fuller (ADF) test in small samples. Table 1 presents the values obtained for each variable from the set of unit root tests. The results provide mixed evidence, indicating stationarity in at least one of the applied tests for each series. For the DF-GLS test, a specification including a constant and no trend was adopted, since the variables are expressed in logarithms and, according to graphical inspection, fluctuate around a constant mean without displaying a clear deterministic trend. It is acknowledged that unit root tests exhibit low statistical power in small samples; therefore, the results should be interpreted with caution and in conjunction with other elements of the econometric analysis.

Given the limited sample size, the results must be interpreted with caution, as residual-based cointegration tests may exhibit low statistical power in small samples. Dynamic multicollinearity may increase the variance of individual estimators and affect their statistical significance; however, it does not introduce bias into the estimated coefficients nor invalidate the interpretation of short- and long-run relationships when evidence of cointegration exists. Its potential presence is therefore acknowledged as an inherent limitation of the adopted dynamic framework. Upon applying the Bounds Test within the Autoregressive Distributed Lag (ARDL) approach, considering the four variables included in the model, an F-statistic of 5.8245 (p-value=0.006783) is obtained, allowing for the rejection of the null hypothesis of no cointegration. The computed statistic exceeds the upper critical bound I(1) values reported by Pesaran *et al.* (2001), thereby supporting the existence of a long-run equilibrium relationship among the analyzed variables. The associated p-value (0.006783) further reinforces this evidence. Nevertheless, given the limited sample length, the Bounds Test results must be interpreted prudently. The analysis is confined to identifying the presence of such a relationship and does not explicitly address

Table 1. Auxiliary Estimation of Unit Root Tests.

Variable	ADF (p-value)	KPSS (p-value)	ADF-GLS F-Statistic	ADF-GLS (p-value)	Test Statistic
Production (lnY)	0.725	0.100	1.359	0.317	-2.440 <CV
Harvested Area (lnSSe)	0.750	0.044	0.679	0.650	-1.687 >CV
Labor (lnMO)	0.173	0.100	1.945	0.173	-2.794 <CV
Nitrogen (lnNitro)	0.707	0.028	0.468	0.792	-1.091 >CV

short-run dynamics through an Error Correction Model (ECM). The estimation of the ECM is beyond the scope of the present study. In light of the cointegration evidence under the ARDL framework, the empirical estimation proceeds through a log-linear Ordinary Least Squares (OLS) model to obtain average long-run elasticities. This approach does not aim to capture the full short-run dynamics or the speed of adjustment toward equilibrium; rather, it seeks to provide a parsimonious and structurally coherent approximation of the long-run relationship among the variables.

RESULTS AND DISCUSSION

The analysis based on growth rates enables the evaluation of short-run dynamics among the variables. Agricultural production theory establishes a causal direction from harvested area, labor, and nitrogen use toward output determination. Growth rates facilitate the examination of short-term changes; thus, causal relationships among variables can be inferred in a temporal and partial manner, while a fully structural approach remains beyond the scope of this section. The calculation of the period growth rate and the average annual growth rate is presented in Table 2. A negative growth rate of -40.67% is observed for harvested area, with an average annual growth rate of -2.03% . Similarly, rice production exhibits a negative growth rate of -9.86% and an average annual growth rate of -0.49% . This negative coevolution is consistent with a short-run causal mechanism in which the contraction of the land factor precedes and partially explains the decline in output. The economically active population in the primary sector displays a positive growth rate of 0.57% and an average annual growth rate of 0.03% , reflecting short-run rigidity in the labor factor. Given the pronounced decline in production, these results suggest that labor is unlikely to constitute the principal causal factor underlying output variation during the analyzed period. Nitrogen fertilizer use presents a positive growth rate of 8.05% and an average annual growth rate of 0.40% , despite the simultaneous decline in production. This pattern indicates that the increase in input use was insufficient to offset the contraction in harvested area, thereby pointing to an indirect and conditional causal effect of fertilizer application.

When interpreted through growth rates, the identified causality must be regarded as indicative and confined to the short run, without implying a strict structural causal relationship. Harvested area emerges as the principal causal factor behind the decline in production; labor assumes a largely passive role during the period, and nitrogen use, although increasing, proves incapable of reversing the downward trajectory of output. Overall, the evidence suggests a causality predominantly driven by extensive changes (land area) rather than intensive factors. Nevertheless, this interpretation warrants caution, as it derives from descriptive growth rates rather than from an explicitly identified structural

Table 2. Period Growth Rate (PGR) and Average Annual Growth Rate (AAGR).

Variable/Rate	Production (Y)	Harvested Area (S _{Se})	Population (PEA _a)	Nitrogen (N)
PGR	-9.86%	-40.57%	0.57%	8.05%
AAGR	-0.49%	-2.03%	0.03%	0.40%

model. The magnitude of the negative growth rates observed particularly in harvested area suggests the presence of a structural break during the 2011-2013 period, which altered the underlying trend behavior of the productive variables. This break may be interpreted as an exogenous or institutional shock, potentially associated with changes in production incentives, adverse climatic conditions, or land-use reallocation affecting the land factor. From a causal perspective, the decline in production would therefore not reflect a gradual adjustment of inputs, but rather a discrete shift in the production regime, where adjustment occurred primarily through the extensive margin. The nearly inertial behavior of the agricultural economically active population reinforces this interpretation by discounting labor as the source of the break, while the simultaneous increase in nitrogen use suggests a compensatory mechanism that ultimately failed to counteract the negative impact of the structural disruption on output. In this context, the structural break constitutes a key causal determinant that conditions the observed growth rates and constrains the validity of interpretations based on a stable input-output relationship throughout the entire period.

Based on the econometric evaluation, the variables included in the log-log Cobb-Douglas specification are statistically significant according to the Student's t-test at a 95% confidence level. The coefficient of determination (R^2) is 0.796, indicating that the model explains approximately 79.64% of the variation in rice production. The results are presented in Table 3. Furthermore, the estimated parameters exhibit the theoretically expected signs for the explanatory variables, thereby confirming consistency with agricultural production theory.

The estimated regression model is:

$$\hat{Y}_l = 1.15 \times 10^{-8} + 0.825 Sse_i + 1.276 PEAa_i + 0.4586 N_i \tag{5}$$

And the estimated Cobb-Douglas production function is:

$$\hat{Y}_l = 1.15 \times 10^{-8} \left(SSe^{0.825} PEA_i^{1.276} N_i^{0.4586} \right) \tag{6}$$

Because the regression is specified in logarithms, the estimated parameters can be interpreted directly as elasticities. The following ceteris paribus effects are observed:

- A 1% increase in harvested rice area is associated with a 0.825% increase in rice production. Thus, rice output exhibits diminishing marginal returns with respect to the land factor.

Table 3. Model parameters and statistical significance.

Variable	Estimated Parameter	Standard Error	t-Value	Prob> t
Intercept	-18.2837	8.715519	-2.10	0.052
lnSSe	0.825909	0.107363	7.69	0.000
lnNitro	0.458698	0.144882	3.17	0.006
lnMO	1.276668	0.536724	2.38	0.030
R^2	0.7964			

- A 1% increase in the economically active population in the primary sector is associated with a 1.276% increase in rice production, indicating increasing marginal returns with respect to labor.
- A 1% increase in total nitrogen fertilizer use is associated with a 0.4586% increase in rice production. Therefore, rice output exhibits diminishing marginal returns with respect to the capital proxy.

The sum of rice production elasticities is given by $0.825 + 1.276 + 0.4586 = 2.5596$, which exceeds unity and suggests increasing returns to scale within the estimated econometric model.

Since the sum of the estimated elasticities is greater than one (2.5596), increasing returns to scale are inferred. However, this relationship reflects aggregated econometric behavior and does not allow for a conclusive inference regarding a specific stage of the production process, as the estimation does not explicitly identify technological or structural conditions of the production system. Table 4 presents the results of the statistical evaluation, including the corresponding diagnostic tests.

The diagnostic tests indicate normally distributed residuals according to the Jarque-Bera and Shapiro-Wilk tests. To assess residual autocorrelation, the Breusch-Godfrey test suggests no evidence of serial correlation. Although the Durbin-Watson statistic indicates autocorrelation, the LM test corroborates the absence of first-order autocorrelation. Homoskedasticity is supported by the Breusch-Pagan test. In addition, the Variance

Table 4. Results of the rice production model tests.

Test	Statistical	Diagnostic
Jarque Bera	JB=0.50089	Normality in errors
	p-value=0.7785	
Shapiro-Wilk	W=0.96406	Normality in errors
	p-value=0.62774	
Breusch-Godfrey	p-value=0.3936	No autocorrelation
Durbin Watson	DW= 1.101	Autocorrelation
	p-value=0.002898	
LM-test	LM test=2.2654	No autocorrelation at one lag
	p-value=0.1323	
Breusch-Pagan test	BP=4.1268	Homoscedasticity
	p-value=0.2481	
VIF	INSse= 1.85; INPEAa= 1.81; INNitro= 1.21	Multicollinearity Values <10
Ramsey	RESET=4.1409	Model specification
	Prob>F=0.0599	

InSse=logarithms harvested rice area; InNitro=logarithms nitrogen; InMo=logaritms population; JB=Jarque Bera; W=Shapiro-Wilk statistic; DW=Durbin Watson; LM=Lagrange Multiplier test; BP=Breusch-Pagan test; VIF=Variance Inflation Factor, and RESET: Ramsey RESET test.

Inflation Factor (VIF) results indicate no evidence of severe multicollinearity among the independent variables.

The Ramsey RESET test points to a potential model misspecification; although the null hypothesis is not rejected at the 5% level, the result lies near the threshold, suggesting that the model may be omitting nonlinearities, interaction terms, or other relevant variables. Overall, the model is deemed efficient within the limits of an abstract and parsimonious specification. The study confirms a decline in both rice production and harvested area, consistent with Reyes *et al.* (2024), who analyze the rice market in Mexico and document a structural relationship associated with the contraction of cultivated area. The findings are also aligned with Ireta *et al.* (2016), who report a negative effect of area on rice production (-7.7), suggesting land-use-related production constraints. In contrast, these results differ from Caicedo *et al.* (2019) and Rivera *et al.* (2015), who argue that production expansion does not depend primarily on cultivated area but rather on yield improvements. A key limitation is that rice is the second highest-yielding cereal nationally; moreover, the gap between sown and harvested area, together with sensitivity to climatic variability, introduces additional uncertainty into the area-production relationship an important constraint acknowledged but not explicitly modeled in this study. Harvested area is identified as the second-most influential variable in rice production, with an estimated elasticity of 0.825. This positive effect is conditioned by the heterogeneity of production systems, which imposes additional constraints on crop expansion. In Mexico, rice-growing regions operate under distinct technological regimes, including flood irrigation in central and southern regions, direct seeding under irrigation in northern and western regions, and rainfed cultivation in the southeast (Favilla & Herrera, 2023).

These technological differences substantially affect productivity; however, they are not incorporated explicitly in the empirical analysis in accordance with the principle of econometric parsimony, favoring a simple specification estimable with a short sample. Consequently, the estimated coefficients should be interpreted as average elasticities conditional on an implicit technological level. From the econometric evaluation, the variable with the largest positive impact is the economically active population in the agricultural sector (1.276), implying a more-than-proportional association with rice output. Notably, agricultural labor participation has exhibited a downward trend in employment generation, consistent with García and Omaña (2001), who identify a negative composition effect: structural change in the productive system reduced employment levels at a rate of -0.2% annually, reflecting limited absorption capacity in agricultural employment. The result for the economically active population differs from Pérez *et al.* (2019), who find a negative relationship with production (-2.274%), attributing it to an oversupply of workers in the agricultural sector.

It also contrasts with evidence reported by Zhu *et al.* (2024), in which the rural economically active population plays a critical role in reducing rice cultivation intensity. In the present study, the computed growth rate of the agricultural economically active population (0.5%) may be linked to rural-urban migration and the persistence of labor informality phenomena that reduce labor retention in the primary sector and constrain short-run expansion, as documented for the Mexican context (Lara *et al.*, 2020). Regarding

nitrogen dynamics, the estimated impact on rice production is comparatively smaller, reflecting less than one percentage point in output response to a 1% increase in nitrogen use. Although fertilizer is a productive input with a positive effect, Mexico is characterized by substantial dependence on imports, reaching 67.1% (Gaucín & Torres, 2011). Tosquy *et al.* (2008) report that the use of nitrogen fertilizers can increase rice production costs by up to 27%. In the literature, studies linking rice and fertilizer often emphasize price elasticities; for example, Reyes *et al.* (2024) estimate -0.2 , and Guzmán *et al.* (2019) report -0.32 for bean cultivation. It is also estimated that the expansion of high-yield programs promoted excessive use of chemical nitrogen fertilizers (González, 2017, p. 1743). Given the selection of proxy variables particularly the economically active population and nitrogen use the analysis faces constraints derived from limited empirical documentation, which restricts the depth with which the results can be contrasted and contextualized.

CONCLUSIONS

The study demonstrates a sustained contraction in both rice production and harvested area, alongside a positive output response to production inputs. The estimates reflect associations and should not be interpreted as strict causal relationships. The estimated relevance of labor, harvested area, and nitrogen use is conditioned by the use of proxy variables, the omission of technological factors, and the aggregated nature of available information. Therefore, while the findings are consistent with economic theory, they remain subject to limitations stemming from sample size, data availability, and the scarcity of crop-specific empirical evidence.

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