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Analysis of irrigated and rainfed rice production in Mexico, 1980-2022*

Análisis de la producción de arroz bajo riego y temporal en Mexico, 1980-2022

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Abstract

Introduction. From 2016 to 2022, both the planted area and rice production in Mexico registered decreasing growth rates, leading to an increase in rice imports to satisfy the excess demand. **Objective.** To econometrically analyze the factors affecting rice production in Mexico by technology type, distinguishing between irrigated and rainfed systems. **Materials and methods.** A dynamic simultaneous equation model was formulated, comprising two supply equations, three price transmission models and one identity; with annual data from 1980 to 2022 on rice production in Mexico (differentiated by technology type), as well as the prices of competitive products, tradable inputs and climatic variables that determine them. To estimate the model, the Two-Stage Least Squares (2SLS) method was used and its statistical congruence was determined by means of the global significance of each equation through the F-test, its level of autocorrelation via the Durbin-Watson statistic, the individual significance of each coefficient through the Student's t-test, and the normality of the variables with the Shapiro-Wilk test. **Results.** The own-price elasticities of supply for irrigated and rainfed rice were 0.6995 and 0.3871, respectively. The prices of competitive goods, particularly corn (-0.9896 and -1.2284) and wheat (-0.5279 and -0.9529), had the greatest impact on both types of supply. **Conclusion.** The rice supply, both irrigated and rainfed, responds positively to changes in producer prices, water availability for irrigation, and the annual average rainfall recorded in the country. Conversely, it responds negatively to changes in producer prices of competitive goods such as beans, corn, wheat, lentils and chickpeas, as well as to change in inputs such as the price of pesticides and fertilizers.

Keywords: Elasticities of supply, irrigation, rainfed crops, simulation.

Resumen

Introducción. De 2016 a 2022, tanto la superficie sembrada como la producción de arroz en México registraron tasas de crecimiento decrecientes, lo que ocasionó un aumento de las importaciones de arroz para atender el exceso de demanda. **Objetivo.** Evaluar econométricamente los factores que afectan la producción de arroz en México por tipo de tecnología, diferenciada en riego y temporal. **Materiales y métodos.** Se formuló un modelo de ecuaciones simultáneas dinámicas, compuesto por dos ecuaciones de oferta, tres de transmisión de precios y una identidad; con datos anuales de 1980 a 2022 de la producción de arroz en México (diferenciada por tipo de tecnología), así como los precios de productos competitivos, insumos comerciables y variables climáticas que las determinan. Para la estimación del modelo se utilizó el método de mínimos cuadrados en dos etapas (MC2E) y su congruencia estadística se determinó por medio de la significancia global de cada ecuación a través de la prueba *F*, su nivel de auto correlación vía el estadístico Durbin Watson, la significancia individual de cada coeficiente a través de la *t* de Student y la normalidad de las variables con la prueba Shapiro-Wilk. **Resultados.** Las elasticidades precio-propias de la oferta de arroz en riego y temporal fueron de 0,6995 y 0,3871, respectivamente. Los precios de los bienes competitivos, particularmente el maíz (-0,9896 y -1,2284) y el trigo (-0,5279 y -0,9529), tuvieron el mayor impacto en ambos tipos de oferta. **Conclusión.** La oferta de arroz, tanto de riego como de secano, responde positivamente a los cambios en los precios al productor, la disponibilidad de agua para riego y la precipitación media anual registrada en el país y se observaron respuestas negativas a los cambios en los precios al productor de bienes competitivos como frijol, maíz, trigo, lenteja y garbanzo, y en insumos como el precio de plaguicidas y fertilizantes.

Palabras clave: elasticidades de la oferta, riego, cultivo de temporal, simulación.

Introduction

World rice production from 2016 to 2022 registered an average annual growth rate (AAGR) of 0.8%, which meant an increase of 36.1 million metric tons (Mt) during the period. China has historically been the world's leading rice producer. In 2022, global rice production surpassed 776.4 million Mt, with China and India being the main producers with 26.85 % and 25.27 %, respectively, followed by Bangladesh (7.37 %), Indonesia (7.05 %), Vietnam (5.5 %), Thailand (4.42 %), Myanmar (3.18 %), the Philippines (2.54 %), Cambodia (1.5 %), Pakistan (1.41 %), Brazil (1.39 %), and Japan (1.33 %). Mexico accounted for only 0.03% of global production. Among these countries, India recorded the highest AAGR (2.98 %) from 2016 to 2022, followed by Cambodia (2.62 %) and Bangladesh (2.11 %), while Myanmar experienced the lowest rate (-0.92 %) (Food and Agriculture Organization of the United Nations [FAO], n. d.).

In 2022, rice exports from the five main exporting countries reached 2.78 million tons, which represented only 0.36 % of global production. The United States led the export market with 31.55 %, followed by Brazil (30.8 %), India (15.1 %), Uruguay (9.38 %), and Paraguay (4.29 %). Regarding imports, the top five importing countries in 2022 acquired 1.99 Mt (0.26 % of global production), with Vietnam (18.9 %), Nepal (14.77 %), Mexico (13.53 %), Venezuela (9.62 %) and Costa Rica (5.73 %). From 2016 to 2022, Vietnam experienced the highest AAGR in imports at 72.32 %, followed by Nepal (25.82 %) and Costa Rica (9.53 %), while Mexico registered a decrease in its import growth rate of 8.53 % (FAO, n. d.).

In Mexico, the area planted with rice in 2022 was 37994 ha, of which 78.51 % was under irrigation and the rest was planted under rainfed conditions. The largest irrigated area was recorded in Nayarit (37.41 % or 11160 ha), followed by the states of Campeche (19.61 %), Michoacán (12.96 %), Jalisco (10.83 %), Veracruz (6.52 %), and Tamaulipas (6.15 %), totaling 27887 ha. The largest rainfed areas were in Campeche (30.74 %), Veracruz (23.41

%), Colima (22.4 %), Nayarit (15.52 %), and Tabasco (3.64 %), which together accounted for 7815 ha (Servicio de Información Agroalimentaria y Pesquera [SIAP], s. f.).

In 2022, Mexico's rice production reached 246317 t, with 84.83 % coming from irrigated areas and 15.17 % from rainfed areas. The leading irrigated producers were Nayarit (32.7 %), Campeche (16.32 %), Michoacán (16.01 %), Veracruz (10.8 %) and Jalisco (10.27 %), producing a total of 179913 t. The main rainfed producers were Campeche (32.75 %), Colima (26.27 %), Veracruz (21.92 %) and Nayarit (14.54 %), contributing a total of 35683 t (SIAP, s. f.).

In terms of yield per hectare of rice in 2022, the national average was 7.6 t/ha for irrigated rice and 3.71 t/ha for rainfed. There were significant yield differences among producing states within each water regime, The irrigated yield range was 6.27 t/ha (Veracruz 11.6 t/ha and Colima 5.33 t/ha), while the rainfed range was of 3.71 t/ha (Colima 5.37 t/ha and Chiapas 1.66 t/ha) (SIAP, s. f.).

From 2016 to 2022, both the planted area and rice production in Mexico experienced declining AAGRs of 1.44 and 0.51 %, respectively, which indicates an increased dependence on foreign rice. In 2022, the agricultural sector's total national production in Mexico reached 884876 million pesos, with rice accounting for only 0.17%. While these figures indicate a low economic importance of rice in Mexico, it ranks fourth among dietary staples (after corn, wheat, and beans), with an annual per capita consumption of 8.9 kg (SIAP, s. f.). This also reflects the country's dependence on imports, registering 431,427 tons in 2022, which represented 1.75 times the national production (FAO, n. d.). This highlights the need to strengthen trade relations with supplier countries such as Uruguay, Paraguay, India, Thailand, and Cambodia, with which Mexico still maintains tariff barriers, and to improve internal productivity conditions (Favila Tello & Herrera Corral, 2023).

The hypothesis was that the supply of irrigated and rainfed rice is positively influenced by producer prices, water availability for irrigation, and average rainfall, and negatively affected by the prices of competitive products and inputs, with the effect on price transmission being less than proportional. The objective of this study was to evaluate the factors affecting rice production in Mexico by technology type, differentiating between irrigation and rainfed systems.

Materials and methods

A dynamic simultaneous equations model was formulated, composed of two Nerlove supply equations, three price transmission models, and an identity. It used annual data from 1980 to 2022 on rice production in Mexico (differentiated by technology type), as well as the prices of competing products, tradable inputs, and the climatic variables that determine them.

Newlove's dynamic econometric models are autoregressive (AR) and/or distributed lag (DL) models. A distributed lag model is a regression analysis that contains time series information, where the regression model incorporates both the current values and lagged (past) values of the explanatory variables (equation 1). An autoregressive model includes one or more lagged values of the dependent variable among its explanatory variables (equation 2) (Gujarati & Porter, 2010):

$$Y_t = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + u_t \qquad \text{equation 1}$$

$$Y_t = \alpha + \beta X_t + \gamma Y_{t-1} + u_t \qquad \text{equation 2}$$

Both are considered dynamic models because they track the trajectory of the dependent variable over time, relative to its past values, a common practice in econometric analysis.

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In economics, the effect of a variable Y (dependent) on another variable X (explanatory) is rarely immediate and requires time to manifest. Y responds to X after a period called a lag. It represents the effect of a unitary change in X on Y at time t and in subsequent periods (equation 3) (Gujarati & Porter, 2010):

$$Yt = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \cdots + \beta_k X_{t-k} + u_t \qquad \text{equation 3}$$

The above function represents a distributed lag model with a finite lag of K periods. The coefficient β_0 is the short-run or impact multiplier, showing the change in the average value of Y caused by a unit change in X within the same period. If X remains unchanged, $(\beta_0 + \beta_1)$ represents the average in Y in the next period, $(\beta_0 + \beta_1 + \beta_2)$ in the subsequent period, and so on. This is referred to as the long-run or total distributed lag multiplier. A system of simultaneous equations can be expressed in condensed matrix form (equation 4), as proposed by Gujarati & Porter (2010).

$$\Gamma Y_t + BX_t = E_t \qquad \text{equation 4}$$

Where: Y_t = Vector of endogenous variables of the model; X_t = Vector of predetermined variables, plus the ordinate to the origin; G = Matrix of structural parameters associated with the endogenous variables; B = Matrix of structural parameters associated with the predetermined variables; E = Vector of random error terms. The vectors Y_t and E_t are of order $m \times 1$, where m is the number of endogenous variables in the model. For its part, G is a square matrix of order $m \times m$. In turn, B is a matrix of order $k+1 \times m$, where k is the number of lagged exogenous and endogenous variables of the model plus the ordinate to the origin; In general, k may or may not be equal to m. Since the inverse of G exists, it is possible to derive the reduced model of the system (equation 5).

$$Y_t = \Pi X_t + V_t \qquad \text{equation 5}$$

Where: $\Pi = -\Gamma^{-1} B$ is the matrix of the parameters of the reduced form; $V_t = -\Gamma^{-1} E_t$ is the matrix of the perturbations of the reduced form.

The model

The relationship between the determinants of rice supply in Mexico, differentiated by technology type, was established through economic elasticities, calculated from the results of a simultaneous equations model. The structural form was formulated as follows: equations 6 and 7 model milled rice production in Mexico under irrigation and rainfed conditions respectively.

$$QPARI_t = \alpha_{11} + \alpha_{12}\, PMRARIRL_{t-1} + \alpha_{13}\, PMRFRIRL_{t-1} + \alpha_{14}\, PMRMRIR_t + \alpha_{15}\, PMRTRIR_t + \alpha_{16}\, PMRLRIR_t + \alpha_{17}\, PMRGRIR_t + \alpha_{18}\, PFERTR2L_{t-2} + \alpha_{19}\, PPLAGR_t + \alpha_{110}\, PMORL_{t-1} + \alpha_{111}\, DAR_t + \alpha_{112}\, TEMP_t + \alpha_{113}\, QPARIL_{t-1} + \varepsilon_{1t} \qquad \text{equation 6}$$

Where: $QPARI_t$ = amount of irrigated rice in Mexico (t); $PMRARIRL_{t-1}$ = real rural average price of irrigated rice with a lag of one year ($/t); $PMRFRIRL_{t-1}$ = real rural average price of irrigated beans with a lag of one year ($/t); $PMRMRIR_t$ = real rural average price of irrigated corn ($/t); $PMRTRIR_t$ = real rural average price of irrigated wheat ($/t); $PMRLRIR_t$ = real rural average price of lentils produced under irrigation ($/t); $PMRGRIR_t$ = real rural average price of irrigated chickpeas ($/t); $PFERTR2L_{t-2}$ = real price of fertilizer with a lag of two years ($/t); $PPLAGR_t$ = real price of the pesticide ($/t); $PMORL_{t-1}$ = actual labor price with a lag of one year ($/t); DAR_t =

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availability of water for irrigation (millions of m^3); $TEMP_t$ = annual average temperature (°C) and $QPARIL_{t-1}$ = amount of irrigated rice in Mexico with a lag of one year (t).

$$QPATE_t = \alpha_{21} + \alpha_{22}\ PMRATER3L_{t-3} + \alpha_{23}\ PMRFTER3L_{t-3} + \alpha_{24}\ PMRMTER_t + \alpha_{25}\ PMRTTER^t + \alpha_{26}\ PMRLTER2L_{t-2} + \alpha_{27}\ PMRGTER_t + \alpha_{28}\ PFERTR2L_{t-2} + \alpha_{29}\ PPLAGRL_{t-1} + \alpha_{210}\ PMORL_{t-1} + \alpha_{211}\ PP_t + \alpha_{212}\ TEMP_t + \alpha_{213}\ QPATEL_{t-1} + \varepsilon_{2t} \quad \text{equation 7}$$

Where: $QPATE_t$ = amount of rainfed rice in Mexico (t); $PMRATER3L_{t-3}$ = real rural average price of rainfed rice with a lag of three years ($/t); $PMRFTER3L_{t-3}$ = real rural average price of rainfed beans with a lag of three years ($/t); $PMRMTER_t$ = real rural average price of rainfed corn ($/t); $PMRTTER_t$ = real rural average price of wheat produced in rainy season ($/t); $PMRLTER2L_{t-2}$ = real rural average price of rainfed lentils with a lag of two years ($/t); $PMRGTER_t$ = real rural average price of rainfed chickpeas conditions ($/t); $PFERTR2L_{t-2}$ = real price of fertilizer with a lag of two years ($/t); $PPLAGRL_{t-1}$ = real price of the pesticide with a lag of one year ($/t); $PMORL_{t-1}$ = actual labor price with a lag of one year ($/t); PP_t = average annual precipitation (mm); $TEMP_t$ = annual average temperature (°C) and $QPATEL_{t-1}$ = amount of rice produced in rainy season in Mexico with a lag of one year (t).

The equations 8 and 9 model the transmission effect of the wholesale price of rice in Mexico has on the rural prices of irrigated and rainfed rice.

$$PMRARIR_t = \alpha_{31} + \alpha_{32}\ PMAYAR3L_{t-3} + \alpha_{33}\ Dt + \varepsilon_{3t} \quad \text{equation 8}$$

Where: $PMRARIR_t$ = real rural average price of rice produced under irrigation ($/t); $PMAYAR3L_{t-3}$= real wholesale price of rice with a lag of three years ($/t) and D_t = classification variable with zero from 1980 to 1986 (closed economy period) and one from 1987 to 2022 (open economy).

$$PMRATER_t = \alpha_{41} + \alpha_{42}\ PMAYAR3L_{t-3} + \alpha_{43}\ D_t + \varepsilon_{4t} \quad \text{equation 9}$$

Where: $PMRATERL_t$ = real rural average price of rice produced in rainfed crops ($/t); $PMAYAR3L_{t-3}$= real wholesale price of rice with a lag of three years ($/t) and D_t = classification variable with zero from 1980 to 1986 (closed economy period) and one from 1987 to 2022 (open economy).

The equation 10 models the effect of transportation costs and the producer price of rice in China have on the wholesale price in Mexico.

$$PMAYAR_t = \alpha_{51} + \alpha_{52}\ CTRANSRL_{t-1} + \alpha_{53}\ PINTACHR_t + \alpha_{54}\ D_t + e_{5t} \quad \text{equation 10}$$

Where: $PMAYAR_t$ = real wholesale price of rice ($/t); $CTRANSRL_{t-1}$ = real transportation cost with a lag of one year ($/t); $PINTACHR_t$ = real international price of rice - proxy variable the producer price of rice in China ($/t) and D_t = classification variable with zero from 1980 to 1986 (closed economy period) and one from 1987 to 2022 (open economy).

Finally, the equation 11 defines the total quantity of rice produced in Mexico as the sum of irrigated and rainfed production:

$$QPA_t = QPARI_t + QPATE_t \quad \text{equation 11}$$

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Where: QPA_t = total produced amount of rice in Mexico (t); $QPARI_t$ = amount of rice produced under irrigation in Mexico (t) and $QPATE_t$ = amount of rainfed rice produced in Mexico (t).

This model was based on evidence from empirical research works that have econometrically analyzed the production of this cereal, as well as other agricultural products, including works by Cap et al. (2006), Cutts and Hassan (2003), Guzmán-Soria et al. (2012), Guzmán-Soria et al. (2019), Imai et al. (2011), Khan et al. (2019), McKay et al. (1999), Mundlak et al. (1989), Mythili (2006), Ramírez-Gómez et al. (2004), Rao (1989), Shepherd (2006), Tchereni and Tchereni (2013), Tenaye (2020) and Thiele (2000).

Annual time series data from 1980 to 2022 was used for the variables. Since supply or demand responses to market changes are rarely instantaneous, particularly in agricultural products, where biological process require time, lag periods of one, two or up to three years were assumed for certain exogenous variables, based on their statistical significance (Guzmán-Soria et al., 2012).

Data

The quantities produced and rural average prices were obtained from the Servicio de Información Agroalimentaria y Pesquera (s. f.). Fertilizer and pesticides prices were obtained from the Consejo Nacional Agropecuario (1995) and the Food and Agriculture Organization of the United Nations (n. d.). Water availability for irrigation was obtained from the Comisión Nacional del Agua (s. f.) and the Centro Virtual de Información sobre el Agua (s. f.). Temperature and precipitation data were provided by the Servicio Meteorológico Nacional (s. f.). The wholesale price of rice in Mexico was sourced from the Sistema Nacional de Información e Integración de Mercados (s. f.), and the price of rice in China was obtained from the Food and Agriculture Organization of the United Nations (n. d.). Transportation costs were obtained from the Subsecretaría de Trasporte (s. f.) and the Cámara Nacional del Autotransporte de Carga (s. f.).

Monetary values were calculated in real terms using the Producer Price Index of the Agricultural Sector, the National Consumer Price Index, and the National Consumer Price Index of the Transportation Sector, obtained from the Banco de Información Económica del Instituto Nacional de Estadística y Geografía (s. f.). The base year of the price indices was 2019.

Estimate

The model coefficients were estimated using the Two-Stage Least Squares (2SLS) method (Gujarati & Porter, 2010; Wooldridge, 2009), with the SAS (Statistical Analysis System) version 9.0 software (SAS Institute, 2002). Statistical congruence was assessed through the F-test for the global significance of each equation, the Durbin-Watson (DW) statistic for autocorrelation, Student's t-test for the individual significance of each coefficient, and the Shapiro-Wilk test (SW) for normality (Guzmán-Soria et al., 2012). The sign of each coefficient was validated based on microeconomic supply theory (Parkin & Loría, 2015; Samuelson & Nordhaus, 2010). Based on Gujarati and Porter (2010), order and range conditions were used to identify the model, and the result was that all equations are overidentified.

Results

The five regression equations exhibited high adjusted coefficients of determination (R^2 Adjusted) ranging from 0.87 to 0.94. The F-test results were significant at the 0.01 level, indicating the overall robustness of the models.

The Durbin-Watson (WS) statistic values (1.99 to 2.38) indicate a low autocorrelation between the time series, while the Shapiro-Wilk (SW) values per variable (0.94 to 0.99) imply a near-normal distribution. The intercepts of the two supply equations are negative, which indicate the deficit in national rice production (Tables 1 and 2).

Table 1. Results of the structural form of the two rice (*Oryza sativa*) production equations in Mexico. 1980-2022.

Cuadro 1. Resultados de la forma estructural de las dos ecuaciones de producción de arroz (*Oryza sativa*) en México. 1980-2022.

Exogenous Variables	Endogenous Variable QPARI				
	Parameters	**Sd. error**	***t***	**SW**	**$R^2 = 0.93$**
Intercept	-809660	513375	-1.58*		R^2 Ajust = 0.87
PMRARIRL	28.44	10.17	2.80***	0.96	Pr > F = 0.00
PMRFRIRL	-4.90	2.17	-2.26*	0.92	DW = 2.38
PMRMRIR	-44.62	18.44	-2.42**	0.94	BP = 1.89
PMRTRIR	-25.49	13.69	-1.86**	0.93	
PMRLRIR	-9.22	2.53	-3.64***	0.96	
PMRGRIR	-6.20	3.72	-1.67*	0.94	
PFERTR2L	-4.84	1.54	-3.14***	0.97	
PPLAGR	-9.33	2.96	3.6***	0.95	
PMORL	-638.78	418.28	-1.53*	0.96	
DAR	13.16	2.85	4.61***	0.97	
TEMP	-81314.28	26663.34	-3.05***	0.93	
QPARIL	0.39	0.12	3.20***	0.95	
Exogenous Variables	**Endogenous Variable QPATE**				
	Parameters	**Sd. error**	***t***	**SW**	**$R^2 = 0.98$**
Intercept	-733536	350721	2.09*		R^2 Ajust = 0.94
PMRATER3L	8.45	4.36	1.94*	0.95	Pr > F = 0.00
PMRFTER3L	-1.68	1.43	-1.18*	0.91	DW = 2.32
PMRMTER	-27.35	10.03	-2.73***	0.93	BP = 1.88
PMRTTER	-23.77	10.23	-2.32**	0,93	
PMRLTER2L	-2.09	1.43	-1.46*	0,92	
PMRGTER	-4.63	1.95	-2.38**	0,94	
PFERTR2L	-10.01	8.55	1.17*	0,96	
PPLAGRL	-2.67	1.20	-2.22**	0.96	
PMORL	-259.67	209.35	-1.24*	0.97	
PP	150.46	66.27	2.27**	0.93	
TEMP	-25349.50	14979.08	-1.69*	0.95	
QPATEL	0.73	0.1497	4.86***	0.94	

BP = Breusch-Pagan, heteroscedasticity test between time series. *t* values at 0,1 (*); 0,05 (**); 0,01 (***) of statistical significance. / **BP** = Breush-Pagan, prueba de heterocedasticidad entre las series de tiempo. Valores *t* al 0,1 (*); 0,05 (**); 0,01 (***) de significancia estadística.

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Table 2. Results of the structural form of the three price transmission equations in rice (*Oryza sativa*) production in Mexico. 1980-2022.

Cuadro 2. Resultados de la forma estructural de las tres ecuaciones de transmisión de precios en la producción de arroz (*Oryza sativa*) en México. 1980-2022.

Exogenous Variables	Endogenous Variable PMRARIR				
	Parameters	**Sd. error**	***t***	**SW**	**R^2 = 0.97**
Intercept	4042.50	1044.19	3.87***		R^2 Ajust = 0.94
PMAYAR3L	0.39	0.10	3.81***	0.96	Pr > F = 0.00
D	-808.75	702.66	-1.15*	0.94	DW = 1.99; BP = 1.88
Exogenous Variables	**Endogenous Variable PMRATER**				
	Parameters	**Sd. error**	***t***	**SW**	**R^2 = 0.94**
Intercept	3786.22	107.83	3.51***		R^2Ajust = 0.90
PMAYAR3L	0.42	0.11	3.97***	0.95	Pr > F = 0.00
D	-2178.55	1256.79	-1.73**	0.96	DW=2.08; BP = 1.88
Exogenous Variables	**Endogenous Variable PMAYAR**				
	Parameters	**Sd. error**	***t***	**SW**	**R^2 = 0.94**
Intercept	5817.75	659.21	8.83***		R^2Ajust = 0.92
CTRANSRL	3.48	3.48	7.78***	0.95	Pr > F = 0.00
PINTACHR	0.08	0.03	2.67**	0.93	DW = 2.27
D	-2177.50	545.09	-3.99***	0.96	BP = 1.89

BP= Breusch-Pagan, heteroscedasticity test between time series. *t* values at 0.1 (*); 0.05 (**); 0.01 (***) of statistical significance. / **BP=** Breush-Pagan, prueba de heterocedasticidad entre las series de tiempo. Valores *t* al 0,1 (*); 0,05 (**); 0,01 (***) de significancia estadística.

The coefficients of the reduced form of the model in relation to the total quantity of rice produced (QPA) are reported in Table 3. The Student's *t-test* indicates that the exogenous variables' coefficients are statistically significant, with signs consistent with the microeconomic theory of supply.

Table 3. Results of the reduced form of the rice (*Oryza sativa*) production model in Mexico. 1980-2022.

Cuadro 3. Resultados de la forma reducida del modelo de la producción de arroz (*Oryza sativa*) en México. 1980-2022.

Endogenous variables	Exogenous variables					
	Intercept	PMRARIRL	PMRFRIRL	PMRMRIR	PMRTRIR	PMRLRIR
QPA	-76124.60	28.44	-4.90	-44.62	-25.49	-9.22
	PMRGRIR	PFERTR2L	PPLAGR	PMORL	DAR	TEMP
QPA	-6.201993	-14.85	-9.33	-898.45	13.16	-55964.77
	QPARIL	PMRATER3L	PMRFTER3L	PMRMTER	PMRTTER	PMRLTER2L
QPA	0.39	8.45	-1.68	-27.35	-23.77	-2.09
	PMRGTER	PPLAGRL	PP	QPATEL		
QPA	-4.63	-2.67	150.46	0.73		

Short-run elasticities

Rainfed rice production in Mexico is less elastic (0.3871) compared to irrigated rice (0.6995), implying that production adjusts less than proportionally to changes in the respective producer prices. The total rice supply in

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the country (QPA), considering irrigated and rainfed production, is less impacted by unitary variations in the real producer price of irrigated rice (0.4596) compared to the real producer price of rainfed rice (0.1327).

Regarding price transmission, a 1 % change in the real wholesale price of rice (PMAYAR) causes a greater relative adjustment in the real producer price of rainfed rice (0.46 %), compared to irrigated rice (0.41 %). Furthermore, concerning the effect of the transportation cost (CTRANSR) and the international price of rice (PINTACHR) on the wholesale price of rice in Mexico, a 1 % change in CTRANSR and PINTACHR would cause a direct adjustment in PMAYAR of 0.21 % and 0.10 %; this highlights the impact that the transportation cost has on the marketing margins of rice in Mexico (Table 4).

Table 4. Own and transmission price elasticities of rice (*Oryza sativa*) production prices in the short term in Mexico. 1980-2022.

Cuadro 4. Elasticidades precio propias y de transmisión de los precios de la producción de arroz (*Oryza sativa*) en el corto plazo en México. 1980-2022.

Exogenous Variables	Endogenous variables					
	QPARI	**QPATE**	**PMRARIR**	**PMRATER**	**PMAYAR**	**QPA**
PMRARIRL	0.6995					0.4596
PMRATER3L		0.3871				0.1327
PMAYAR3L			0.4081	0.4554		
CTRANSRL					0.2117	
PINTACHR					0.1038	

Other factors impacting QPA include the price of irrigated corn (PMRMRIR) and the average temperature (TEMP), with elasticities of –0.6502 and –3.3980, respectively. Increases in the real prices of pesticides (PPLAGR) and labor (PMORL) negatively impact QPA at a rate of 0.6539 and 0.2786 %. A 1 % increase in the price of competitive products obtained under rainfed conditions (beans [PMRFTER], lentils [PMRLTER], wheat [PMRTTER] and chickpeas [PMRGTER]) negatively impacts QPA (–0.0733, –0.0912, –0.3268 and –0.1369) (Table 5).

Table 5. Elasticities related to other factors that affect rice (*Oryza sativa*) production in the short term in Mexico. 1980-2022.

Cuadro 5. Elasticidades relacionadas con otros factores que afectan la producción de arroz (*Oryza sativa*) en el corto plazo en México. 1980-2022.

Endogenous variables	Exogenous variables					
	PMRFRIRL	PMRMRIR	PMRTRIR	PMRLRIR	PMRGRIR	PFERTR2L
QPARI	–0,3603	–0,9896	–0,5279	–0,4178	–0,4008	–0,0434
QPA	–0,2367	–0,6502	–0,3469	–0,2745	–0,2633	–0,0875
	PPLAGR	PMORL	DAR	TEMP	QPARIL	
QPARI	–0,9951	–0,3015	2,0329	–7,5140	0,3902	
QPA	–0,6539	–0,2786	1,3357	–3,3980	0,2564	
	PMRFTER3L	PMRMTER	PMRTTER	PMRLTER2L	PMRGTER	PFERTR2L
QPATE	–0,2138	–1,2284	–0,9529	–0,2659	–0,3993	–0,1719
QPA	–0,0733	–0,4213	–0,3268	–0,0912	–0,1369	–0,0875
	PPLAGRL	PMORL	PP	TEMP	QPATEL	
QPATE	–0,5470	–0,2348	0,9822	–4,4881	0,7393	
QPA	–0,1876	–0,2786	0,3368	–3,3980	0,2535	

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Irrigated rice production (QPARI) reacts negatively and almost proportionally to a unit increase in the real price of pesticide (PPLAGR) and is similarly sensitive to the price of irrigated corn (PMRMRIR). On the other hand, a 1 % increase in fertilizer prices reduces QPARI by 0.04 %, while irrigation water availability increases QPARI by 2.03 %. Based on the calculated elasticities with respect to the factors PPLAGR, PMRMRIR, PFERTR, DAR and their AARGs, which for the period 2016-2022 were 6.51, 11.79, 6.51 and −0.65 %, these would generate changes in irrigated rice production in the order of −6.48; −11.67; −0.26 and −1.32 %.

Although the factors that most influence rainfed rice production (QPATE) are the average rural price of corn (PMRMTER), the producer price of wheat (PMRTTER), the price of pesticides (PPLAGR), the average temperature in Mexico [TEMP], and the average precipitation [PP], it should be noted that these last two variables cannot be influenced, as they are stochastic. Based on the elasticities calculated with respect to these factors and their AARGs, which for the period 2016-2022 were 9.57, 6.83, 6.51, 1.02 and −1.08 %, changes in rice production obtained during rainfed seasons would be generated in the order of −11.76, −6.51, −3.56, −4.58 and −1.06 %.

Long-run elasticities

QPARI will respond elastically in the long run to changes in its own real producer price (PMRARIR), as will QPATE. A 1 % increase in the producer price of corn obtained under irrigation and rainfed will reduce the respective rice production by 1.62 and 4.51 %. For irrigated rice production, 1 % increases in input prices reduce supply by 1.63 and 0.07 % in relation to the price of pesticides and the price of fertilizers, respectively. The availability of water for irrigation (DAR) has a positive impact on the respective rice supply at a rate of 3.33 % for every 1% increase in DAR. Temperature and average precipitation in Mexico have an inverse and direct impact on rainfed rice production at a rate of 16.46 and 3.6 % for every 1 % increase in these stochastic explanatory variables (Table 6).

Table 6. Long-term elasticities of rice production in the long term of rice (*Oryza sativa*) production in Mexico. 1980-2022.

Cuadro 6. Elasticidades de la producción de arroz (*Oryza sativa*) en el largo plazo en México. 1980-2022.

Endogenous variables	**Exogenous variables**					
	PMRARIRL	PMRFRIRL	PMRMRIR	PMRTRIR	PMRLRIR	PMRGRIR
QPARI	1,1455	–0,5899	–1,6205	–0,8645	–0,6842	–0,6563
	PFERTR2L	PPLAGR	PMORL	DAR	TEMP	QPARIL
	–0,0711	–1,6296	–0,4937	3,3290	–12,3048	0,6390
QPATE	PMRATER3L	PMRFTER3L	PMRMTER	PMRTTER	PMRLTER2L	PMRGTER
	1,4197	–0,7842	–4,5053	–3,4949	–0,9753	–1,4646
	PFERTR2L	PPLAGRL	PMORL	PP	TEMP	QPATEL
	–0,6306	–2,0062	–0,8612	3,6023	–16,4610	2,7114

Discussion

Regarding short-run elasticities (2 to 3 years), those calculated in this work were consistent with the aggregate elasticities of agricultural products (including rice) in the short term from 1958 to 1982 obtained by Rao (1989) for developed and developing countries such as China, India, Bangladesh, Thailand, Malaysia, Turkey, Sudan, the Philippines, Japan, and the United States, which were in the order of 0 to 0.8. Although these are not price elasticities per se, but elasticities respecting the cultivated area, which were higher than the elasticities calculated in relation to the yield.

Based on the economic elasticities estimated in this study with respect to PMRARIR and PMRATER in the short term, if their Average Annual Growth Rates (AAGRs) observed from 2016 to 2022 (7.54% and 8.60%, respectively) continue, irrigated and rainfed rice production are projected to increase by 5.27% and 3.33%, respectively, resulting in overall increases in total rice production in Mexico of 3.47% and 1.14%.

Between 2016 and 2022, PMRMRIR and TEMP recorded AAGRs of 11.79% and 1.02%, respectively, which would lead to reductions in QPA of −7.67% and −3.47%. The negative impact of exogenous variables under irrigation technology—such as PMRFRIRL, PMRLRIR, PMRTRIR, and PMRGRIR—is significantly greater than the effect of their counterparts under rainfed conditions.

It is worth noting that although water is essential for rice cultivation, as rice is known to be a semi-aquatic crop, Mexico faces a significant water scarcity issue. As a result, rice varieties that do not require constant flooding are cultivated, and in rainfed areas, varieties adapted to such water conditions are used.

The price elasticity of irrigated rice production was found to be more inelastic compared to the price elasticity of beans (0.9087) estimated by Guzmán-Soria et al. (2019), and similar to the elasticity calculated for rainfed bean production (0.3771).

The price elasticity of rainfed rice production was found to be close to the aggregate elasticity of food crops, including rice, which McKay et al. (1999) found for Tanzania at 0.35 and to the same type of aggregate elasticity calculated by Mundlak et al. (1989) for Argentina in the period from 1913 to 1984, which was 0.43. Although this comparison between results that are not entirely equivalent is limiting, in terms of economic elasticities, it helps measure the magnitude of change between variables.

In Colombia, Ramírez-Gómez et al. (2004) found a price elasticity of production for rice of 0.28, using a logarithmic model and annual information from 1970 to 2002; the result of this calculated elasticity is closer to the respective elasticity calculated here for rainfed rice production.

Compared to maize cultivation, the price elasticity of supply of rainfed rice is close to that reported by Cutts and Hassan (2003) for Zimbabwe (0.3605) and is much higher than that reported for Malawi (0.0924), Mozambique (0.0439), Tanzania (0.0631), South Africa (0.0938) and Zambia (0.0708). The comparison between the economic elasticities of production of maize and rice lies in their importance in the national diet.

Of the price elasticities for wheat, maize and soybean production calculated by Cap et al. (2006) for some MERCOSUR (South American Common Market) countries, the one calculated for wheat in Argentina (0.429) and maize in Brazil (0.28) are the closest to that found in this work for rainfed rice production and the one calculated for maize in Bolivia (0.62) and wheat in Brazil (0.86) are the closest to that found in this work for irrigated rice production. For 10 Asian countries, Imai et al. (2011) found price elasticities of supply for agricultural commodities in the range of 0.015 to 0.309, the upper limit of this range being somewhat lower than the two calculated in this work.

Regarding long-run elasticities (5 to 6 years), calculated for aggregate prices (including rice) and individual prices of some agricultural products reported for the period 1958 to 1982 in developed and developing countries such as China, India, Bangladesh, Thailand, Chile, Malaysia, Turkey, Sudan, Argentina, the Philippines, Japan and the USA, ranges from 0.3 to 1.2 (Rao, 1989). The own-price elasticity of rainfed rice supply calculated here was within the range, but the irrigated rice supply was higher (1.4197).

For Tanzania and Argentina, long-run aggregate supply price elasticities of food crops (including rice) were found to be 0.98 and 0.99 (McKay et al., 1999; Mundlak et al. 1989), which differs from the two larger price elasticities of rice supply calculated in this study; 1.1455 for irrigated rice production and 1.4197 for rainfed rice production. This comparison helps understand the impact and magnitude between these variables.

On the other hand, for Colombia, a long-term price elasticity of rice production of 0.93 was calculated using a logarithmic model (Ramírez-Gómez et al., 2004). This elasticity is closer to the calculated for irrigated rice production in Mexico, which was 1.1455.

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Finally, it is worth highlighting that the two long-term own price elasticities calculated in this work (1.1455 and 1.4197) are significantly higher than those for Zimbabwe (0.4484), Malawi (0.1331), Mozambique (0.0667), Tanzania (0.1339), South Africa (0.1519) and Zambia (0.1694) reported by Cutts and Hassan (2003).

The econometric analysis of rice production in Mexico is relevant, considering that it is the fourth most consumed staple food in the country, and this directly relates to national food security.

Conclusions

The rice supply, both irrigated and rainfed, respond positively to changes in producer prices, water availability for irrigation, and average annual rainfall recorded in the country. Conversely, negative responses were observed to changes in producer prices of competitive goods such as beans, corn, wheat, lentils and chickpeas, as well as inputs such as the price of pesticides and fertilizers.

The total supply of rice in Mexico responds inelastically to changes in the producer price for rice produced under irrigation and rainfed conditions, which partly reflects producers' inability to increase their rice supply in response to increased demand during the analysis period. The level of own-price inelasticity was found to be higher in the supply of rice under irrigation than in rainfed conditions. This inelastic supply of rice in the country demonstrates that irrigated and rainfed producers are unable to adjust their production in response to price changes. Furthermore, the changes in producer prices of competitive elements that affect the total supply of rice are primarily those registered for corn and wheat, produced under irrigation.

The price transmission effect indicates less than proportional adjustments for the wholesale price on the producer price of irrigated rice and on the producer price of rainfed rice. Significantly, international price changes exert a smaller influence on the wholesale price of rice compared to the impact of transportation costs. Despite the limited influence that the wholesale price or transportation costs have on the producer price of rice, these factors do not constitute sufficient incentives given the limitations on adjusting production capacity in the country.

The research tested the hypothesis that the supply of irrigated and rainfed rice is positively influenced by producer prices, water availability for irrigation, and average rainfall, and negatively affected by the prices of competitive products and inputs, with the effect on price transmission being less than proportional. Based on the results of the model, the hypothesis could not be rejected.

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Interests conflict

There is no conflict of interest.

References

Cap, E. J., Brescia, V. P., Lema, D. R., Berges, M., Casellas, K., Menezes, T., Piketty, M-G., Melo, O., Murguia, J. M., García, F., Caputi, P., & Lanfranco, B. (2006). *Mercosur + 2: Estimation of supply and demand elasticities of agricultural products. projection to 2012 of baseline supply scenarios*. National Institute of Agricultural Technology.

Cámara Nacional del Autotransporte de Carga. (s. f.). *Estadísticas e indicadores del autotransporte de carga: 1980-2022*. Gaceta Económica de la Cámara Nacional del Autotransporte de Carga.

Centro Virtual de Información sobre el Agua. (s. f.). *Situación de las presas en México*. Retrieved January 12, 2025 from https://agua.org.mx/categoria/informes-estadisticos/

Comisión Nacional del Agua. (s. f.). *Estadísticas del agua en México: 1980-2022*. Sistema de Información Nacional del Agua de la Comisión Nacional del Agua.

Consejo Nacional Agropecuario. (1995). *Compendio estadístico del Sector Agroalimentario: Precio promedio LAB (estación de ferrocarril) de los fertilizantes y producción nacional*. Consejo Coordinador Empresarial.

Cutts, M., & Hassan, R. (2003, October 2-3). An econometric model of the SADC maize sector [Contributed paper]. *41st Annual Conference of the Agricultural Economic Association of South Africa (AEASA)*, Pretoria, South Africa. http://ageconsearch.umn.edu/bitstream/19075/1/cp03cu01.pdf

Favila Tello, A., & Herrera Corral, M. A. (2023). Competitividad Internacional del Arroz Mexicano: un análisis con base en datos de comercio exterior. *RECAI Revista de Estudios en Contaduría, Administración e Informática, 12*(35), 18–31. https://doi.org/10.36677/recai.v12i35.21268

Food and Agriculture Organization of the United Nations. (n. d.). *FAOSTAT- Production, trade and prices*. Retrieved January 21, 2024 from https://www.fao.org/faostat/en/#data/QCL

Gujarati, D. N., & Porter, D. C. (2010). *Econometría* (5ª ed.). McGraw-Hill.

Guzmán-Soria, E., De la Garza-Carranza, M. T., García-Salazar, J. A., Hernández-Martínez, J., & Rebollar-Rebollar, S. (2012). Determinantes de la oferta de maíz grano en México. *Agronomía Mesoamericana, 23*(2), 269–279. https://doi.org/10.15517/am.v23i2.6488

Guzmán-Soria, E., De la Garza-Carranza, M. T., García-Salazar, J. A., Rebollar-Rebollar, S., & Hernández-Martínez, J. (2019). Determinantes de la oferta de frijol por tipo de tecnología en México. *Investigación y Ciencia de la Universidad Autónoma de Aguascalientes, 27*(76), 49–59. https://doi.org/10.33064/iycuaa2019761791

Imai, K. S., Gaiha, R., & Thapa, G. (2011). Supply response to changes in agricultural commodity prices in Asian countries. *Journal of Asian Economics, 22*(1), 61–75. http://dx.doi.org/10.1016/j.asieco.2010.08.002

Instituto Nacional de Estadística y Geografía. (s. f.). *Precios e inflación*. Retrieved January 19, 2024 from https://www.inegi.org.mx/temas/inpp/

Khan, S. U, Faisal, M. A., Haq, Z. U., Fahad, S., Ali, G., Khan, A. A., & Khan, I. (2019). Supply response of rice using time series data: Lessons from Khyber Pakhtunkhwa Province, Pakistan. *Journal of the Saudi Society of Agricultural Science 18*(4), 458–461. https://doi.org/10.1016/j.jssas.2018.03.001

McKay, A., Morrissey, O., & Vaillant, C. (1999). Aggregate supply response in Tanzanian agriculture. *The Journal of International Trade & Economic Development 8*(1), 107–123. https://doi.org/10.1080/09638199900000008

Mundlak, Y., Cavallo, D., & Domenech, R. (1989). *Agriculture and Economic Growth in Argentina: 1913-84*. International Food Policy Research Institute. https://ageconsearch.umn.edu/record/42166/?v=pdf

Mythili, G. (2006). *Supply Response of Indian Farmers: Pre and Post Reforms*. Indira Gandhi Institute of Development Research. http://www.igidr.ac.in/pdf/publication/WP-2006-009.pdf

Parkin, M., & Loría, E. (2015). *Microeconomía. Versión para Latinoamérica* (11ª ed.). Pearson Educación.

Ramírez-Gómez, M., Martínez-Covaleda, H. J., Ortiz-Hermida, L. X., González-Rodríguez, F. A., & Barrios-Urrutia, C. A. (2004). *Respuestas de la oferta y la demanda agrícola en el marco de un TLC con Estados Unidos* [Documento de trabajo No. 49 Observatorio Agrocadenas Colombia]. Ministerio de Agricultura y Desarrollo Rural de Colombia. https://repositorio.iica.int/items/c61339f5-68a2-4d29-a6c1-9be05223e3ae/full

Rao, J. M. (1989). Agricultural supply response: A survey. *Agricultural Economics, 3*(1), 1–22. https://doi.org/10.1016/0169-5150(89)90036-4

Samuelson, P. A., & Nordhaus, W. D. (2010). *Microeconomía con aplicaciones a Latinoamérica* (19ª ed.). McGraw-Hill.

SAS Institute. (2002). *2SLS Procedure in SAS System version 9.0*. SAS Institute.

Servicio Meteorológico Nacional. (s. f.). *Temperatura y Precipitación media anual por estado y nacional*. Retrieved January 27, 2024 from https://smn.conagua.gob.mx/es/climatologia/temperaturas-y-lluvias/resumenes-mensuales-de-temperaturas-y-lluvias

Shepherd, B. (2006). *Estimating price elasticities of supply for cotton: A structural time-series approach*. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-ah470e.pdf

Servicio de Información Agroalimentaria y Pesquera. (s. f.). *Sistema de Información del Sector Agrícola: 1980-2022*. Retrieved January 29, 2024 from https://www.gob.mx/siap/documentos/siacon-ng-161430

Sistema Nacional de Información e Integración de Mercados. (s. f.). *Precio del arroz en las centrales de abastos del Distrito Federal y Área Metropolitana*. Retrieved February 5, 2024 from http://www.economia-sniim.gob.mx/nuevo/Home.aspx?opcion=Consultas/MercadosNacionales/PreciosDeMercado/Agricolas/ConsultaGranos.aspx?SubOpcion=6|0

Subsecretaría de Trasporte. (s.f.). *Estadísticas de Transporte de América del norte: 1980-2022*. Secretaría de Comunicaciones y Transporte.

Tchereni, B. H., & Tchereni, T. H. (2013). Response of maize to price and non-price incentives in Malawi. *Journal of Economics and Sustainable Development, 4*(5), 141–152. https://core.ac.uk/download/pdf/234645895.pdf

Tenaye, A. (2020). New evidence using a dynamic panel data approach: Cereal supply response in smallholder agriculture in Ethiopia. *Economies, 8*(3), Article 61. https://doi.org/10.3390/economies8030061

Thiele, R. (2000). *Estimating the aggregate agricultural supply response: a survey of techniques and results for developing countries* (Kiel Working Papers No. 1016). Kiel Institute of World Economics. http://hdl.handle.net/10419/2516

Wooldridge, J. M. (2009). *Introducción a la econometría: Un enfoque moderno* (4ª ed.). CENGAGE Learning.