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Article

Regional differences in rainfed white corn production in Mexico

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Abstract

This research aims to identify the functional form that best represents the production of rainfed white corn in Mexico. Two variants of the constant elasticity of substitution function and the Cobb-Douglas function were tested using a cross-sectional sample of 10 924 corn farmers obtained from the 'questionnaire to collect the 2008 baseline: SAGARPA programs'. The analysis was performed at national and regional levels using fourteen factors of production. The results show that the Cobb-Douglas model provides better fits and estimators consistent with theoretical principles. Similarly, it is shown that the use and effect of each production factor on the yield of rainfed white corn is different between the regions of the country, so it was shown that public policy actions should be differentiated based on the needs and particularities of each region. An analysis of the effect of each input at the regional level and a discussion of the possible effects of some support programs for the agricultural sector focused on a particular input are presented.

Keywords:

agricultural policy, Cobb-Douglas function, white corn production.

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Introduction

White corn in Mexico is primarily grown in the spring-summer (SS) agricultural cycle, in which it reaches up to 74.5% of arable land and almost 86% of national production (FIRA, 2016). This production cycle is characterized by a high proportion of producers who use traditional and inefficient production systems, concentrated in small productive units, with low endowments of productive assets, a significant technological lag, limited organization, and high climate vulnerability (Yúnez, 2014).

These factors exacerbate the deficiencies of traditional production systems, reduce the possibility of forming economies of scale and scope, and contribute to environmental deterioration (CONEVAL, 2015). In addition, there are significant differences in the productive conditions of farmers in the different regions of the country that produce rainfed white corn. For example, in the northern regions, under mechanized and irrigated systems, yields are three to five times higher than the national average and almost 12 times higher than that of producers using traditional systems.

In contrast, in the center and south of the country, 67% of producers work in rainfed lands, without access to credit, with limited capacities, and mostly for self-consumption (González-Estrada, 2010). In this context, a regional analysis of the role played by the different production factors of rainfed white corn is relevant, an analysis that is commonly carried out in crops of economic or cultural relevance with the use of production functions.

The three most used functional forms to represent the production of a crop are: 1). Cobb-Douglas (CD), the advantage of which is that it considers the technological asymmetries between the various farmers, which allows evaluating the use of inputs of the productive systems (Yúnez, 2014); 2). Constant elasticity of substitution (CES), a function that is less restrictive than CD, although occasionally more difficult to estimate (Galarza-Díaz, 2015); and 3). Translog, a function resulting from a second-order approximation of a CES function, with the enormous disadvantage that the number of parameters increases exponentially with increasing the number of production factors considered, with the consequent problems of collinearity in the estimation (Pavelescu, 2011).

This research had two objectives: i) to identify the functional form that best represents the production of rainfed white corn in Mexico; and ii) to compare the use of inputs and production systems and identify inputs that could improve production levels in each region. The results and lessons learned from this research are relevant since they establish a reference framework to study the production of this grain in Mexico and to highlight the needs, deficiencies, and competencies in the use of the main inputs in each region of the country.

Materials and methods

Data

The database (DB) was built from the 'questionnaire to collect the 2008 baseline: SAGARPA programs' (SAGARPA, 2009). This DB contains cross-sectional information by producer, at the national level, and with an independent sampling framework for each state. The information includes production, use of inputs, production characteristics, costs, productive capacity, and public benefits of agricultural, livestock, and aquaculture producers in Mexico in 2008. Methodological details and characteristics of the DB are shown in CTEEA-UAA (2009).

The working DB joint the different databases of producers at the state level. The total production units (PUs) used in the analysis were 10 925, which includes producers who grew rainfed white corn during the 2008 SS cycle as a primary or associated crop. This database was enriched with state-level climate information obtained from the National Weather Service.

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Method

The methodology consisted of testing different functional ways to model white corn production at the regional level. The regions were defined according to the stratification defined by Arroyo (1987), which preserves the political division at the state level and allows differentiating the agricultural regions. The regions are Northwest (Baja California, Baja California Sur, Nayarit, Sinaloa, and Sonora), North (Chihuahua, Durango, Coahuila, and Zacatecas), Northeast (Nuevo León and Tamaulipas), Central-West (Jalisco, Guanajuato, Michoacán, Aguascalientes, and Querétaro), Central-South (Puebla, Tlaxcala, Hidalgo, State of Mexico, Mexico City, and Morelos), Gulf (Veracruz and Tabasco), South Pacific (Colima, Guerrero, Oaxaca, and Chiapas) and Peninsula (Yucatán, Campeche and Quintana Roo).

The analysis only considered the CD and CES models. In the case of the CES function, a model with returns to scale was tested. Returns to scale show the relationship between increases in output achieved after increases in all factors of production (inputs).- constant (CES-K) and equal to one and a CES function with fluctuating returns to scale (CES-F). The CD model was estimated from the following linearized functional form (1) and the fit was made through the robust ordinary least squares method with the use of the statistical package STATA-16.0 (StataCorp, 2019), both regionally and nationally.

$$\ln Y_{ij}= \beta_0+\delta_1\ln M_i+\delta_2\ln FL_i+\delta_3\ln HL_i+\delta_4\ln L_i+\delta_5\ln K_i+\delta_6\ln Ir_i+\delta_7\ln Cred_i+\ln Temp_j+\delta_9\ln pp_j+ \varepsilon_{i.}$$

1).

Where: Y_{ij} is the total production of white corn in tonnes (t), obtained in production unit i, which produces in region j. M_i is a vector of materials used in production, including seeds (kg), fertilizers (kg), herbicides (L), and pesticides (L). FL_i represents unpaid labor from the family of producer i, and HL_i corresponds to the contracted work, both measured in eight-hour wages L_i. is the size of the plot cultivated with corn (ha). K_i represents a vector of assets used in production, which includes the number of warehouses, tractors, threshers, harvesters, and pickup trucks used in production. $Cred_i$ is a dichotomous variable that determines access to credit.

The variables $Temp_j$ and pp_j show the maximum temperature (°C) and average precipitation (mm) in region j during the months of the 2008 SS cycle. Finally, $\#_0$ is the efficiency parameter, referred to as the set of unobservable characteristics in the other variables that affect production, while #k is the product elasticity of the k-th input.

The estimation of the CES function was made from the logarithmic transformation (2) and the fit was made with robust non-linear least squares with the statistical package STATA-16.0, both at regional and national level.

$$\ln Y_{ij}= \beta_0+\frac{\gamma}{\rho}\ln\left[\alpha_1 M_i\rho+\alpha_2 FL_i\rho+\alpha_3 HL_i\rho+\alpha_4 L_i\rho+\alpha_5 K_i\rho+\alpha_6 Ir_i\rho+\alpha_7 Cred_i\rho+\alpha_8 Temp_j\rho+ \alpha_9 pp_j\rho\right]+ \varepsilon_i$$

2).

Where: the variables have the same meaning as in (1) and ρ represents the parameter associated with the degree of substitution of the factors of production.

The parameter γ is associated with the returns to scale, while $\#_i$ is the parameter that indicates the intensity of use of the i-th input. The variant of CES-K assumes constant returns to scale equal to one (γ= 1),while CES-F relaxes this assumption by considering values of γ≥ 0. In both models, the value of ρ defined the elasticity of substitution (σ). The elasticity of substitution shows the relative change generated by the input in the technical rate of substitution when the quantity of output remains constant; of inputs, defined as σ=1/1+ρ, with the restriction that σ∈[0,∞).

Results and discussion

The analysis with all the information at the national level on the congruence of the estimators (expected sign according to the literature) suggests that the functional form CD better represents the production of white corn in the SS cycle. Additionally, goodness-of-fit statistics (Table 1) show

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that the CD model has better accuracy (higher adjusted R^2 and lower RMSE, AIC, and BIC) since it predicts, at the national level, almost 70% of the variation in the production of rainfed corn.

Table 1. Comparison of accuracy and goodness-of-fit estimators of functional forms for the entire dataset (national analysis).

Functional form	Parameters		Results of estimators at the national level				
	ρ	γ	Adjusted R^2	RMSE	AIC	BIC	JB
CES with constant returns to scale (CES-K)	≈0	1	0.66	0.554	18.106	18.216	$1.2e^4$
CES with fluctuating returns to scale (CES-F)	≈0	≥0	0.679	0.538	17.482	17.599	9573
Cobb-Douglas	0	≥0	0.692	0.527	17.037	17.146	$1.7e^4$

RMSE= root mean squared error; AIC= Akaike information criteria; BIC= Bayesian information criterion; JB= Jarque-Bera test of normality of errors.

This value is high considering that grain production depends on an additional set of factors not observed in the model, such as producer skills, management, and handling of the production unit, among others. Additionally, the fit with the CD model shows a normal distribution of errors judging from the critical value of the Jarque Bera (JB) test.

When the analysis is carried out at the regional level, some regions show that the fit with the CES-Fs or the CES-Ks presents accuracy and goodness of fit marginally higher than those obtained with the CD model, as a result of the expected regional technological differences. Nonetheless, the fits of the CES models show differences in the expected signs.

Therefore, the analysis both at the national level, all states, and regional level shown below only presents the results obtained from the fit with the CD model (Table 2). The estimation with the CD model does not present inconsistencies in the estimators or situations that stand out for their little relationship with the existing literature (Constantin et al., 2009). The nationwide estimate showed that all inputs (except for the contracted labor and thresher) are significant and mostly positive. A consistent result because most corn producers do not use production factors efficiently (Yunez et al., 2006).

Table 2. Corn production function, national and by region under the Cobb-Douglas model§.

	National	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
		Northwest	North	Northeast	CW¤	CS¤	Gulf	SP¤	Peninsula
Seed	0.291***	0.397*	0.195***	0.01	0.359***	0.13**	0.045	0.122***	0.156**
Fertilizer	0.059***	0.149***	0.042***	0.035	0.122***	0.029*	0.041***	0.039***	0.03***
Herbicide	0.053***	-0.064	0.019	0.658***	0.037**	0.032	0.082***	0.042***	0.025
Pesticide	0.049***	-0.041	0.271***	0.056**	0.061***	-0.006	0.014	0.038***	-0.003
Family labor	-0.026***	-0.225***	0.022	-0.122***	-0.016	-0.001	0.037	0.016	-0.015
Contracted labor	-0.008	0.301***	-0.013	0.11***	0.005	0.061**	-0.015	0.038**	0.016

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	National	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8
		Northwest	North	Northeast	CW¤	CS¤	Gulf	SP¤	Peninsula
Plot size	1.075***	1.035***	0.994***	0.848***	1.026***	1.018***	1.054***	1.07***	0.944***
Warehouse	0.191***	-0.494	-0.038	0.064	0.235**	0.435***	0.032	0.147	0.27*
Tractor	0.339***	0.51	0.326***	0.352***	0.44***	0.221*	0.095	0.36	0.589**
Thresher	-0.119	-	0.146	-0.217	-0.263	0.893***	-0.56**	-0.713**	0.474*
Pickup truck	0.286***	0.54***	0.045	0.054	0.29***	0.185*	0.236***	0.232***	0.035
Credit	0.028***	0.024	0.045***	0.011	0.028***	-0.014	0.011	0.028***	0.01
Temperature	0.069	8.348***	2.149***	-	-0.745	1.48***	-	16.2***	0.526
Precipitation	0.197***	0.498***	0.793**	2.18***	-0.161	-0.219	-1.256***	0.314***	0.319**
Constant	-2.463***	-34.27***	-12.04***	-10.27***	1.785	-4.61***	6.513***	-59.78***	-4.076
Observations	10.924	222	1.112	890	2.354	1.661	1.051	2.894	740
R^2	0.692	0.702	0.734	0.801	0.683	0.646	0.791	0.7	0.701
Adjusted R^2	0.692	0.684	0.73	0.798	0.682	0.643	0.789	0.694	0.695
RMSE	0.527	0.641	0.524	0.412	0.701	0.439	0.412	0.414	0.391
Returns to scale	2.541	11.043	4.815	3.891	1.837	4.251	0.158	18.645	2.782
Average prod. (t ha^{-1})	1.39	2.06	1	0.93	2.43	1.31	1.9	1.13	0.85

CW= Central-West; CS= Central-South; SP= South Pacific. §= the Cobb-Douglas estimate assumes #=0. p>|z|: *** p< 0.001, **p< 0.01, *p< 0.05 with robust standard errors. Returns to scale estimated as the sum of significant estimators associated with factors of production. Source: based on data from SAGARPA (2019) and support from STATA-16.0 (StataCorp LLC, 2019). Based on the fit of the CD model.

The analysis of the effect of inputs on corn production at the regional level is presented below. The fits show that seed, plot size, and tractors are the inputs with the greatest effect on corn production. It also identifies effects of materials and assets at the regional level similar to those reported by various authors (Jaramillo-Albuja et al., 2008; González-Estrada, 2010).

The estimate with the CD function showed that white corn production at the national level has increasing returns to scale of 2.54. This implies that, on average, national producers are far from the optimum point of maximum productive efficiency and that, given the conditions in 2008 (reference year), an equal increase in inputs would generate an increase in total production of up to 254%.

Yield

Yield (production per hectare) is markedly different between regions. The high average yields of the Central-West and Northwest regions stand out, where the use of improved germplasm, larger scale of production, and intensive production systems is common. In contrast, the Northeast and Peninsula regions show the lowest yields; both cases associated with rainfed cultivation in areas with environmental limitations, particularly the intra-summer drought in the Yucatán Peninsula (Rangel et al., 2018) and strong technological limitations (Reséndiz et al., 2014).

Plot size

Theory and empirical work in different countries show that land productivity decreases with plot size (Kagin et al., 2016) to a certain scale beyond which productivity increases (Muyanga and Jayne, 2019). However, in the case of Mexico, both positive and negative relationships have been reported (Kagin et al., 2016).

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The results show that plot size has a significant and positive effect on national production and the production of all regions. Its effect can represent up to an elasticity greater than 100% (Northwest, Central-West, Central-South, Gulf, and South Pacific regions), contrasting with the North, Northeast, and Peninsula regions, which show economies of scale less elastic with respect to the size of the plot.

These differences are not only linked to the interaction between scale, physical-environmental variables, and cultivation system (type and quantity of diverse inputs), but also to sociodemographic variables not considered in the analysis, such as education, regional connectivity, access to markets, and migration (Kagin et al., 2016).

Seed

The effect of this factor is positive and significant for almost all regions. In the regions with higher production (Northwest and Central-West), seed has an effect greater than in the rest of the country, derived from the intensity of the production systems used in these regions, an effect that is not shown in other regions where less intensive cultivation systems in the use of inputs are employed and where the use of better quality seed generates additional costs.

It is of interest that, in the Northeast and Gulf regions, the effect of this factor is not significant, which can be attributed to: i) the use of technological packages. The technological packages are made up of a structure of inputs (seed, agrochemicals, and cultivation system) aligned to a cultivation system and physical-environmental condition. In this way, producers use them in the harvest as they are given, regardless of whether it is the necessary amount required by the land or not, not appropriate, or inefficient cultivation systems that make the seed in conjunction with the other inputs and the physical-environmental conditions where they are applied does not have a significant effect on production; and ii) the land is so poor or the production system so inefficient that, despite the availability of better quality seed, it has no effect on production (Reséndiz et al., 2014).

In the case of the Northeast region, Tamaulipas and Nuevo León, the use of inappropriate technology (poor linkage between the inputs used and the physical-environmental conditions) seems to be the most feasible explanation. Nonetheless, in the case of the Gulf region, Veracruz and Tabasco, it is highly likely that the land has reached its production limit and that the quality and quantity of seed have no effect on grain production (Reséndiz et al., 2014). In any case, it seems necessary to improve the genetic material used in the rainfed production in these regions.

Fertilizers, herbicides, and pesticides

The results show that these inputs are not essential for the corn production of low-intensity in the use of inputs, mainly because their use is closely related to the amount of rainfall; nevertheless, their use can have significant increases of 6% in national production, with regional variations.

Fertilizer alone increases corn production by 12% to 15% in two of the regions. Likewise, the use of herbicides and pesticides increases production by up to 65% in the Northeast and by 27% in the North since, as noted above, they are regions of intensive use of technological packages.

However, most small producers in these regions tend not to use these inputs because they do not consider them essential, there is ignorance of their benefit, and they imply additional costs in traditional systems (Flores, 2000). The result suggests the need for an analysis of the economic and technical efficiency of the technological packages used in these regions.

Family labor

This factor has a significant negative effect at the national level and in the Northwest and Northeast regions. The result can be explained by an effect of diminishing returns to scale derived from the rapid reduction in average productivity per agricultural worker (Kagin et al.,

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2016) or because the productivity of labor is not the same when it is not remunerated. Therefore, although family labor is a low- or no-cost input for producers, it is not necessarily entirely efficient.

In any case, the presence of this variable does not affect regional production more than other variables. It is relevant that this variable shows no effect in the North, Central-East, Central-South, Gulf, South Pacific, and Peninsula regions, regions that are characterized by very small-scale production systems and low-input consumption cultivation systems with few cultural activities (Donnet et al., 2017).

Contracted work

The effect of this factor is positive and significant for half of the regions, except for the North, Central-West, Gulf, and Peninsula regions, and even at the national level, there is no effect. It can be hypothesized that the absence of effect of this factor is due to the fact that a small scale of production with extensive agricultural systems does not require additional labor to the family labor force.

Productive assets

The assets (warehouses, tractors, and pickup trucks) have a significant effect on corn production and can increase national production by 20% to 30%. Each asset has different effects at the regional level. The effect of the warehouses is positive and significant at the national level and for the central regions of the country, and Peninsula; with a greater effect in the Central-South.

This effect is associated with the fact that in this region, storage becomes a major problem. On the contrary, the effect of the warehouses is null in the regions of more intensive agriculture, where there is a high availability, and in regions where most of the production is for self-consumption and no storage is required. The estimators associated with the use of tractors are positive and significant both nationally and for most regions, except for the Northwest (the high abundance of tractors has a non-limiting factor effect) and the Gulf and South Pacific (orography limits their use).

There is a greater effect in the Central-West and Peninsula regions, where their use can increase production by up to 60%. This is because they are the regions where there is less presence of tractors, as is the case of the Peninsula, or the productive units are larger and more intensive in the use of inputs, so they need machinery for cultivation (Central-West). The pickup truck has a significant and positive effect nationally and in most regions.

There is a greater effect in the Northwest and Central-West regions, presumably associated with the fact that there are larger scales of production and more intensive cultivation systems are used, so transportation is necessary. The only assets that did not show effect in most regions and nationally are the thresher and harvester. Two possible reasons for this result are: i) the use is replaced by work or some other asset such as tractor; or ii) the proportion of producers in rainfed conditions with this asset is so small that no effect is observed.

However, more research is required in this area to assess the effect or the relationship between the use of these assets and other inputs according to the conditions of the production environment. Credit in the production unit has positive effects at the national level and for the North, Central-East, and South Pacific regions. This factor is usually linked to the purchase of production inputs rather than assets. Ninety-six percent of the PUs analyzed do not have access to this service, so the evaluation of its effect requires additional research.

Finally, precipitation has a negative effect on the Gulf region because it is the region where it rains the most (Aldama et al., 2015). In contrast, in the northern regions, rainfall has a positive effect on production as they are more arid areas. Based on this hypothesis, the South Pacific region contrasts, in which a positive effect of precipitation is observed, which is complemented by a positive effect of temperature.

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This is due to the fact that, in 2008, the meteorological effect known as El Niño (El Niño-Southern Oscillation) occurred, which increased the maximum temperatures of the region and was accompanied by a drought. This combined effect is reflected in the positive effect of precipitation in this region. At the level of each region, some expected patterns can be observed. The South Pacific and Central-South regions show significance in almost all input-output elasticities. This reinforces the perception that in these regions, production systems are very inefficient and any improvement in inputs improves production.

The greatest effect is seen in factors such as machinery, equipment, and seed, where a small proportional change in these inputs substantially improves production. The North and Peninsula regions share elasticities, size of the production plot, less than one, which means that production increases in a decreasing manner with the scale of production. The result coincides with the findings of Kagin et al. (2016), who attribute this effect to the alignment between an inefficient system and the small scale.

The effect seems to be reaffirmed when observing that basic inputs such as labor, pesticides, and herbicides or machinery and equipment (except for tractors) show no effect on production. Nevertheless, it is interesting the strong effect that the presence of tractors has in these regions, a presence that is undoubtedly linked to larger production scales that can presumably generate a positive productivity-scale effect at higher scales, such as the U-shaped effect documented by Muyanga and Jayne (2019).

The Northeast region shares an elasticity, size of the production plot, less than one as in the two previous cases; however, the effect of inputs is important and significant, which shows that, unlike previous regions, it is possible to intervene in production systems and improve the production of white corn (Donnet et al., 2017).

The rainfed corn production system referred to as most common in the Gulf region is minimum tillage (Donnet et al., 2017). The results (Table 2) show alignment with this production system since most of the inputs have no effect on it, except for fertilizers and herbicides. It is also clear that excess precipitation is a major constraint to corn production in the region.

Finally, the regions of highest production, Central-West and Northwest, show that seed and fertilizer have a strong effect on production. These inputs are linked to technological packages, the basis of grain production in these regions, whose use is most evident in the Central-West region (Donnet et al., 2017). It should be noted that in these regions with more intensive systems, the presence of pickup trucks has a significant effect on production.

Estimates of all functional forms showed differences in the use of factors of production between regions. This suggests that it is not advisable to establish a homogeneous public policy throughout the country that seeks to encourage some factor of production equally. The results suggest that the needs, the scale of production, the way in which inputs are used and the sophistication of the production system vary throughout the country. Consequently, the policy of support for farmers cannot be standardized because, inevitably, the allocation of resources will be inefficient (Cortés, 2009).

Thus, for example, the results suggest that public policy to support the production of rainfed corn in the northern regions should focus, mainly, on the acquisition and use of materials (fertilizers, herbicides, and pesticides), as well as on the increase in hired labor wages, due to the important positive effects that both measures have on production. In contrast, asset acquisition and access to credit appear to be more relevant in the central and southern regions.

Finally, these results suggest that public policy aimed at supporting farmers not only considers the effects generated by different inputs, but also the possible explanations for these effects, in order to determine the most appropriate interventions in each region. For example, the lack of significance in the effect of seed in some regions may be due to the fact that producers are efficient in their use, that the seed used is of better quality and other inputs are the limitations, or that there are drawbacks in the productivity of the land.

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A similar situation occurs with the negative effect of credit in the Central-South region, where the result may be due to a moral hazard problem, restricted access for smaller producers or that these resources are used for other crops. In these scenarios, the type of interventions differs considerably depending on the problem identified: therefore, it is necessary to diagnose what the public problem is in each region in order to implement government actions appropriate to the needs.

Conclusions

This work showed that, although the CES production model is more flexible, its level of prediction is not significantly different from that obtained with the Cobb-Douglas model, and the results obtained with the latter are more consistent with the theory than any of the tested variants of the CES model at national and regional level.

The results also show that the use and effect of each production factor on the production of rainfed white corn is different between regions of the country since it depends on the biophysical conditions and the cultivation systems used in each region. This shows that public policy actions must be differentiated based on their needs and particularities.

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Regional differences in rainfed white corn production in Mexico

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