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Article

Funciones de producción para madera aserrada en la Empresa Forestal Comunitaria en México

Sawnwood production functions in the Community Forest Enterprise in Mexico

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Resumen

Se generaron tres modelos de producción para madera aserrada en 35 Empresas Forestales Comunitarias (EFC) de 10 estados de México, que se clasificaron a partir de variables relativas (insumos de producción): continuas y nominales que afectan la productividad. Para el modelo I, la mano de obra (*L*) y el capital (*K*) fueron altamente significativas (p -valor <0.001); en el modelo II, lo fueron *L* y volumen disponible (*VD*); *K* resultó significativa al 0.16 % (p -valor < 0.05); Coeficiente de Aserrío anual (*CA*), Clasificación de madera anual (*CM*), Capacidad instalada de la industria anualmente (*CI*), Número de mujeres en puestos operativos al año (*PO*) y Número de mujeres en puestos de toma de decisiones por año (*PTD*) no incidieron en la productividad (p -valor > 0.05). Para el modelo III *L* y *VD* registraron alta significancia; *K* fue significativa al 0.95 % (p -valor < 0.01); Figura Legal Privada (*FL2*) y Figura Legal Sociedad (*FL3*), lo fueron al 0.1 % (p -valor < 0.001) y 2.9 % (p -valor < 0.05), respectivamente. La competitividad en el uso de los recursos se determinó con el Valor del Producto Marginal (VPM). Se rechazaron las hipótesis de uso no competitivo para *L* en el modelo II (0.1 %); para el modelo III, Ho: $Pmg_{L}-P_{L}=0$ en las EFC de Oaxaca y Quintana Roo (p-valor<0.05); y Ho: $Pmg_{K}-P_{K}=0$ para las de Chiapas y Oaxaca (p-valor<0.01). El VPM para *VD* en los modelos II y III, con datos nacionales, se rechazó Ho: $Pmg_{VD}-P_{VD}=0$ con un nivel de significancia de 0.1 %.

Palabras clave: Competitividad, función *Cobb-Douglas*, modelo econométrico, productividad, rendimiento a escala, valor del producto marginal.

Abstract

Three production models for sawnwood were generated in 35 Community Forest Companies (CFEs) located in 10 states of México, which were classified based on variables related to: production inputs, continuous variables, and nominal variables that affect productivity. For Model I the variables *L* and *K* were highly significant (p-value <0.001). Variables *L* and *VD* in model II were highly significant and variable *K* was significant at 0.16 % (p-value <0.05). The *CA*, *CM*, *CI*, *PO* and *PTD* variables had no effect on productivity. For model III, high significance was obtained for the variables *L* and *VD* (p-value <0.001), *K* was significant at 0.95 % (p-value <0.01), *Figura Legal Privada* (*FL2*) and *Figura Legal Sociedad* (*FL3*) were significant at 0.1 % (p-value <0.001) and 2.9 % (p -value <0.05), respectively. Competitiveness in the use of resources was measured with the Marginal Product Value (MPV). The hypothesis of non-competitive use for input *L* in model II (0.1 %) was rejected. For Model III, Ho $Pmg_{L}-P_{L} = 0$ was rejected in the CFEs located in the states of *Oaxaca* and *Quintana Roo* (p-value <0.05) and Ho: $Pmg_{K}-P_{K} = 0$ was rejected for the CFEs located in *Chiapas* and *Oaxaca* (p-value <0.01). Finally, the MPV for VD in models II and III using aggregated data at the national level Ho: $Pmg_{VD}-P_{VD} = 0$ was rejected (p-value <0.001).

Key words: Competitiveness, Cobb-Douglas function, econometric model, productivity, performance to scale, marginal revenue product.

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Introduction

There are 15 584 *ejidos* and forest communities in Mexico, which are called agrarian nuclei, and which are holders of 45.5 % of the total forest area of the country (62 639 719 ha) (Reyes *et al.*, 2012; Conafor, 2019a; Frey *et al*., 2019). These organizations create Community Forest Companies (CFE) and manage forest resources in order to generate economic, social and environmental benefits to improve their quality of life, without neglecting their financial viability, competitiveness and ecological sustainability in the long run (Frey *et al*., 2019), so it is essential to analyze whether Mexico's CFEs fulfill these purposes.

CFEs have uses and customs that sometimes make expeditious administration difficult and do not easily access credit, so they depend on governmental support granted by the *Comisión Nacional Forestal* (National Forest Commission) (Conafor) to improve their competitiveness and efficiency; these focus on reducing production costs, improving the quality of processes, increasing efficiency and adding value to their products (PNUD, 2017). Frey *et al.* (2019) assessed the effect of these supports and concluded that forest certification has a positive impact on productivity and, consequently, on the total income of the community.

Recent studies on CFE income show results differentiated by great variability, attributable to diversity in size, region, productivity and costs (Cubbage *et al*., 2011, 2015a). In general, CFEs replicate a competitive business model to generate jobs and benefits for their members and communities, and adopt strategies for innovation, certification, alliances, and continuous process improvements. Works such as those of Cubbage *et al.* (2013, 2015a, 2015b) and Frey *et al.* (2019) established that competitiveness is related to the ability of the company (of any type) to penetrate the market or increase its market; this can be estimated through the production costs, income, benefits and sustainability of wood harvesting, which explain its profitability and efficiency. Chandra and Shishodia (2017) and Sasatani (2009) considered that the classical financial indicators (profitability of growth, assets, capital and earnings before interest, taxes, depreciation and amortization), as well as production costs and profitability are essential to measure competitiveness with greater accuracy.

Generally, studies on business competitiveness in Mexico do not address a broad scheme that involves economic, environmental and social aspects as a whole, so the use of updated information (2017-2019) from direct sources, as well as the specification of the nature of the investments and the form of organization of CFEs in the present investigation constitute a novel approach. Its contributions will provide feedback and complement the analysis of the results of the Program for the Strengthening of Sustainable Forest Management with a Landscape Approach (PFMFSP, for its acronym in Spanish) and of other studies such as those already cited by Cubbage *et al.* (2013, 2015a, 2015b) and Frey *et al.* (2019). Economic, environmental and social indicators are part of the PFMFSP strategy to increase competitiveness in a local market whose imports exceed its own supply. In fact, Cubbage *et al.* (2015a; 2015b) identified that what puts the efficiency and sustainability of CFEs in Mexico at risk is precisely the increase in imports of sawn wood.

In the present study, the effect of several factors of the social scope (jobs, position of jobs and gender) and environmental (certification of the chain of custody of forest products and good forest management) on the production and productivity of forest products was measured. CFEs through the theory of the company and sustainable forest development. The first objective of this research consisted in determining Cobb-Douglas type production functions to measure the effect of the variables that affect productivity. The second was to measure competitiveness from the Marginal Product Value and determine performance to scale for such inputs as labor, capital and available volume.

Materials and Methods

Materials

The information came from Conafor's PFMFSP for the years 2017 to 2019, it corresponded to 35 CFEs located in 10 states of Mexico: *Chiapas, Chihuahua, Durango, State of Mexico, Jalisco, Michoacán*, *Oaxaca, Puebla, Quintana Roo* and *Veracruz*, in addition of subsidies that were assigned to CFEs in the same years (Conafor, 2017; 2018; 2019b). The measurement and monitoring of the PFMFSP indicators were grouped into three criteria, which served to identify improvements in competitiveness, market access and gender equality according to the United Nations Development Program (UNDP) (PNUD, 2017).

The subsidies corresponded to the National Forest Program (Pronafor, for its acronym in Spanish) through direct support for investment in the forest industry and commerce, administration, production and marketing, and integration and organization of forest value networks, as well as indirect subsidies for operating expenses, national certifications and international and marketing (Conafor, 2017; 2018; 2019b).

Methods

Production functions

The Cobb-Douglas production function (Q) was used with two production factors: capital (K) and labor (L) given by the model:

$$Q = e^{\beta_0} L^{\beta_1} K^{\beta_2} \qquad (1)$$

Where:

β_i = Function parameters

β_1 = Elasticity of *L*

β_2 = Elasticity *K*

K = Product of the annual installed capacity (in feet table shift^{-1}) by the wear of capital, referred to the machinery depreciation (20 %) and was obtained from the unit production cost (\$ pt^{-1}) in the sawmill process

L = Number of direct jobs per 8-hour shift for 240 working days per year

Model (1) can be linearized by applying the natural logarithm (*ln*), with which the following was obtained:

$$lnQ = \beta_0 + \beta_1 lnL + \beta_2 lnK \qquad (2)$$

Given a set of observations of the *Q*, *K* and *L* variables, in n_i CFE located in state i, the parameters of equation (2) can be estimated from the regression model with mixed effect given by:

$$lnQ_{ij} = u_i + \beta_0 + \beta_1 lnL_{ij} + \beta_2 lnK_{ij} + \epsilon_{ij}, i = 1, \ldots, p, j = 1, \ldots, n_i \qquad (3)$$

Where:

ϵ_{ij} = Normal, independent and identically distributed errors with mean 0 and σ^2 variance

u_i = Normal random effect of the i-th state, with mean 0 and σ_u^2 variance; this term implicitly models the correlation between observations $\rho = \sigma_u^2/(\sigma^2 + \sigma_u^2)$, induced by geographic nearness, common environmental factors and similar socioeconomic conditions

The adjustment of the mixed model (3) was carried out with the lme4 package of the R statistical program (R Core Team, 2020). The Shapiro-Wilk test and the homogeneity of variance of the errors with the Barttlet and Levine homoscedasticity tests were used to verify normality.

The base Model (1) was extended to include other continuous and categorical variables that affect the level of production. In general, the proposed production function, according to Frey *et al.* (2019) was:

$$cQ = e^{\beta_0}\Pi_{i=1}^{m} X_i^{\beta_i}\Pi_{j=1}^{n} Y_j^{\gamma_j}\Pi_{k=1}^{r} e^{\delta_k Z_k} \qquad (4)$$

Where:

Q = Produced quantity in thousands of board feet (Mpt = 1 000 pt) per year

$\beta_0, \beta_i, \gamma_j, \delta_k$ = Function parameters

X_i = Production input quantities

Y_j = Continuous variables that affect productivity

Z_k = Nominal or ordinal variables that affect productivity

Model (4) is an empirical variation of the Cobb-Douglas functional form (Frey *et al.,* 2019) that becomes the linear model of the form:

$$lnQ = \beta_0 + \sum_{i=1}^{m} \beta_i lnX_i + \sum_{j=1}^{n} \gamma_j lnY_j + \sum_{k=1}^{r} \delta_k Z_k \qquad (5)$$

Based on expression (5), three labeled models are defined in order of complexity. With model (6) it is possible to determine the effect of the *K* and *L* production factors; in Model (7) the factors related to the technological level, the availability of wood and the inclusion of women in the production process are added. With Model (8) the effect of subsidies, wood certification and the legal figure with which the CFE is constituted, is evaluated. Thus, by dispensing with the subscripts to simplify the notation, the structure of the regression models to be estimated as extensions of the original model (Eq. 1) is presented below:

$$lnQ = u + \beta_0 + \beta_1 lnL + \beta_2 lnK + \varepsilon \qquad (6)$$

$$lnQ = u + \beta_0 + \beta_1 lnL + \beta_2 lnK + \beta_3 lnVD + \gamma_1 lnCA + \gamma_2 lnCM + \gamma_3 lnCI + \gamma_4 lnPO + \gamma_5 lnPTD + \varepsilon \qquad (7)$$

$$lnQ = u + \beta_0 + \beta_1 lnL + \beta_2 lnK + \beta_3 lnVD + \gamma_1 lnCA + \gamma_2 lnCM + \gamma_3 lnCI + \gamma_4 lnPO + \gamma_5 lnPTD + \delta_1 S + \delta_2 CERT + \delta_3 FL + \varepsilon \qquad (8)$$

Where:

Q = Annual production (Mpt)

L = Work (total jobs per year)

K = Annual capital (Mexican pesos)

VD = Annual available timber volume (roundwood m^3)

CA = Annual sawmill coefficient (%)

CM = Annual timber classification (%)

CI = Annual industry installed capacity (pt shift^{-1})

PO = Number of women per year in operational positions

PTD = Number of women per year in decision-making positions

S = Concept of PRONAFOR subsidies (number of supports year^{-1})

CERT = CoC Certification (0, 1)

FL= Legal figure (FL1= *Ejido* or Community, *FL2* = Private and *FL3* = Society)

To quantify the production of physical units in the sawmill process, the production function was modeled from the models (6, 7 and 8).

Marginal Product Value

In microeconomic theory, a firm is competitive if the marginal product value (MPV) of each input is equal to its price. *MPV* is the additional income that a company obtains for hiring an additional unit of work (*L*) and/or a unit of capital (*K*). That is, if CFEs seek maximum competitiveness, the income generated by an additional unit of input should be equal to its cost; that is, the MPV of the input minus the price will be zero (Salvatore, 1983; Mas *et al*., 1995; Varian, 2006). From equation (4), the competitiveness hypothesis in terms of the value of the marginal product is given by:

$$P_Q\left(\frac{\partial Q(L,K)}{\partial X_f}\right) - P_f = 0 \tag{9}$$

$$P_Q\left[e^{\beta_0}\Pi_{i=1}^{m}X_i^{\beta_i}\Pi_{j=1}^{n}Y_j^{\gamma_j}\Pi_{k=1}^{r}e^{\delta_k Z_k}\right] - P_f = 0 \tag{10}$$

Where:

P_Q = Market price of sawn wood weighted to the national price (\$ pt^{-1})

P_f = Input price (\$ salary^{-1}, \$ capital^{-1}) obtained from the production cost (30 % of the production cost for salary and 20 % of the production cost for capital)

β_0, β_f, γ_j, δ_k= Function parameters

From equation (4), it is also possible to construct the competitiveness hypothesis of the CFE as a function of the MPV for labor (*L*):

$$P_Q\left(\frac{\partial Q(L,K)}{\partial L}\right) - P_L = 0$$

(11)

$$P_Q\left[\alpha_1 Q(L,K)(u+\alpha_0+\alpha_1 lnL+\alpha_2 lnK)^{\frac{1}{\lambda}-1}L^{-1}\right] - P_L = 0$$

In a similar way, the competitiveness hypothesis for the CFE as a function of the *MPV* for capital (*K*) is:

$$P_Q\left(\frac{\partial Q(L,K)}{\partial L}\right) - P_L = 0$$

(12)

$$P_Q\left[\alpha_2 Q(L,K)(u+\alpha_0+\alpha_1 lnL+\alpha_2 lnK)^{\frac{1}{\lambda}-1}K^{-1}\right] - P_K = 0$$

Where:

$p_Q(\frac{\partial Q(L,K)}{\partial L})$ = Marginal product value

PL = Labor price

PK = Capital price

PVD = Price of unit of wood volume

With expressions (11) and (12) the hypotheses for MPV of inputs *L* and *K* and *VD* were tested to determine national and state competitiveness, respectively. To contrast the hypotheses, the Wald test for non-linear restrictions (Greene, 2011) was used by means of the R statistical program (R Core Team, 2020).

Additionally, the hypotheses of Ho: $\beta_k + \beta_L = 1$ were tested to determine constant returns to scale for inputs *K* and *L* (Salvatore, 1983; Gould and Lazear, 1998).

Results

Production functions

The expressions of the final production functions derived from models 6, 7 and 8, given by models I, II and III are listed below:

$$lnQ = -10.371 + 0.690lnL + 0.795lnK \qquad \text{(I)}$$

$$lnQ = -6.382 + 0.475lnL + 0.320lnK + 0.481lnVD \qquad \text{(II)}$$

$$lnQ = -5.724 + 0.442lnL + 0.252lnK + 0.520lnVD + 0.267lnFL1 + 0.781lnFL2 + 0.369lnFL3 \qquad \text{(III)}$$

The values of the parameters per variable for the production functions, the level of significance, the result of the statistical tests and the hypotheses are shown in Table 1; the *p*-value is indicated in parentheses.

Table 1. Cobb-Douglas production functions for sawn wood.

Variable/test	**Model**		
	I	**II**	**III**
ln L	0.690 (0.0)***	0.475 (0.0)***	0.442 (0.0)***
ln K	0.795 (0.0)***	0.320 (0.0016)**	0.252 (0.0095)**
ln VD		0.481 (0.0)***	0.520 (0.0)***
FL1			0.267 (0.0801)
FL2			0.781 (0.001)***
FL3			0.369 (0.029)*
Constant	-10.371 (0.0)***	-6.382 (0.0)***	-5.724 (0.0)***
Statistics			
R^2	0.816	0.848	0.845
F_0^a	0.988 (0.503)	0.990 (0.635)	0.984 (0.248)
Bartlett/Levine[b]	14.685 (0.1)	1.475 (0.168)	1.323 (0.235)
Stadistical test			
F_1^c	23.86 (0.0)***	2.93 (0.0865)	8.56 (0.005)**
$IMg_L\text{-}P_L^d$	2117.497 (0.392)	642.42 (0.012)*	297.183 (0.138)
$IMg_K\text{-}P_K^d$	5.962 (0.471)	0.752 (0.181)	0.752 (0.960)
$IMg_{VD}\text{-}P_{VD}^d$		-708.236(0.0)***	-828.57 (0.0)***

[a]F_o = Shapiro-Wilk normality test, normality is not rejected (*p*-value> 0.001); [b]Homoscedasticity test of variances that indicated that the variance of the residuals is constant (*p*-value> 0.001), for models II and III the hypothesis of homoscedasticity is not rejected; [c]Hypothesis test Ho: $\beta_L + \beta_K = 1$; [d]Hypothesis test: *PmgL-P* = 0 for aggregated data at the national level; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The statistics of the hypothesis test for the *MPV* at the state level for the labor (*L*) and capital (*K*) variables of Model I, are shown in Table 2, with Ho: $Pmg_L\text{-}P_L = 0$ and Ho: $Pmg_K\text{-}P_K = 0$, respectively.

Table 2. Statistics for the *MPV* test with Model I.

State	**MPV_L estimation (*p-val*)**	**MPV_K estimation (*p-val*)**
Chiapas	1 115.438 (0.358)	3.710 (0.497)
Chihuahua	1 034.867 (0.362)	6.386 (0.443)
Durango	4 031.075 0.397	7.680 (0.471)
Edo. México	3 147.397 (0.397)	11.999 (0.430)
Jalisco	2 219.260 (0.372)	5.462 (0.479)
Michoacán	1 943.497 (0.390)	4.186 (0.504)
Oaxaca	1 624.518 (0.424)	1.440 (0.637)
Puebla	2 365.610 (0.385)	6.181 (0.469)
Quintana Roo	3 153.318 (0.373)	7.020 (0.466)
Veracruz	3 092.774 (0.390)	8.878 (0.449)

*$p<0.05$; **p<0.01; ***$p<0.001$.

The statistics of the hypothesis test for the *MPV* at the state level for the labor (*L*), capital (*K*) and *VD* variables of Model II, are shown in Table 2, with Ho: Pmg_L-P_L = 0 and Ho: Pmg_K-P_K = 0, respectively.

Table 3. Statistics for the *MPV* test with Model II.

State	**MPV_L estimation (*p-val*)**	**MPV_K estimation (*p-val*)**	**MPV_{VD} estimation (*p-val*)**
Chiapas	195.653 (0.040)*	-0.1744 (0.491)	-346.505 (0.0009)***
Chihuahua	320.119 (0.053)	0.884 (0.132)	-408.536 (0.0005)***
Durango	1 178.74 (0.006)**	1.0442 (0.150)	-716.938 (0)***
Edo. México	377.987 (0.195)	1.2909 (0.075)	-46.939 (0.799)
Jalisco	356.280 (0.045)*	0.0578 (0.876)	-53.295 (0.723)
Michoacán	507.136 (0.014)*	0.1563 (0.698)	-648.341 (0)***
Oaxaca	461.268 (0.001)***	-0.4049 (0.056)	-776.435 (0)***
Puebla	609.375 (0.005)**	0.6137 (0.205)	-787.506 (0)***
Quintana Roo	927.197 (0.001)***	0.8459 (0.146)	-4007.601 (0)***
Veracruz	784.274 (0.009)**	1.2457 (0.064)	-791.833 (0)***

*$p<0.05$; **$p<0.01$; ***$p<0.001$.

Table 4 shows the hypothesis test statistics for *MPV* at the state level for the *L*, *K* and *VD* variables of Model III, with Pmg_L-P_L = 0; Ho: Pmg_K-P_K = 0; Ho: Pmg_{VD}-P_{VD} = 0, respectively. Unlike Model II, in this model the effect of the legal figure variable at the state level was tested and it was statistically non- significant.

Table 4. Statistics for the *MPV* test with Model III.

State	**MPV_L estimation (*p-val*)**	**MPV_K estimation (*p-val*)**	**MPV_{VD} estimation (*p-val*)**
Chiapas	63.298 (0.383)	-0.538 (0.002)**	-537.153 (0)***
Chihuahua	147.292 (0.227)	0.091 (0.827)	-557.230 (0)***
Durango	698.691 (0.057)	0.293 (0.595)	-771.934 (0)***
Estado de México	-208.213 (0.213)	-0.017 (0.963)	-591.969 (0)***
Jalisco	91.627 (0.471)	-0.4343 (0.069)	-402.964 (0.004)**
Michoacán	267.964 (0.116)	-0.2887 (0.334)	-760.214(0)***
Oaxaca	378.242 (0.016)*	-0.548 (0.004)**	-758.686(0)***
Puebla	283.657 (0.122)	-0.044 (0.901)	-896.420(0)***
Q. Roo	525.086 (0.033)*	0.122 (0.777)	-4253.510 (0)***
Veracruz	248.478 (0.272)	0.201 (0.653)	-945.969 (0)***

*$p<0.05$; **$p<0.01$; ***$p<0.001$.

Discussion

In Model I the *L* and *K* variables in the group of production factors were highly significant (*p*-value <0.001). In addition, in Model II, other variables of this type that determined productivity in the CFEs were *VD* and *L*, while variable *K* was significant at 0.16 % (p-value <0.05). *CA*, *CM*, *CI*, *PO* and *PTD* had no effect on productivity (*p*-value> 0.05), which could be explained by the fact that they do not have a direct relationship with productivity, as they rather refer to the result of market strategies, of technological improvements and gender quota.

The coefficients in a function of the Cobb-Douglas type are the elasticities of the inputs L and K in Models I, II and III (Table 1), and represent the percentage change in the level of output (Q) *versus* percentage changes in labor and capital. The elasticities of inputs L and K to produce a level of output Q (Model I, Table 1), show greater statistical significance than when other variables such as *VD* that affect production and productivity are added to the model (Model II, Table 1). This is relevant if it is decided to use models with more variables that explain the effect on the production of inputs as possible productive improvements in the use of factors. The statistical significance of K variable decreases when adding other variables such as *VD* and *FL* (models II and III, Table 1).

For model III, the factors related to the legal figure (private property and society) represent the percentage increase in the production of sawn wood of an CFE, so that for private companies: $(e^{0.781} - 1)\,100 = 118\ \%$, while for the CFE with a legal status of society: $(e^{0.369} - 1)\,100 = 44\ \%$. This is relevant since *ejidos* and forest communities gather more than 85 % of the forest property regime, in regard to small property and society. The variables *FL1*, *S*, and *C* had no effect on the productivity of the CFE (p-value> 0.05). In future analyzes of this type, it is recommended that monetary values be used for *S* instead of the number of subsidies.

Regarding the analysis of the *MPV* for L and K with the data added at the national level, the hypothesis Ho was rejected: $Pmg_L\text{-}P_L = 0$ for Model II (Table 1) with a level of significance of 0.1 % (p-value < 0.05). It was also determined that there is no statistical significance for the hypotheses Ho: $Pmg_L\text{-}P_L = 0$ and Ho: $Pmg_K\text{-}P_K = 0$ (p-value> 0.05) in the analysis of *MPV* at the state level (Model I, Table 2). For Model I (Table 3) when determining the competitiveness of the CFEs, Ho was rejected: $Pmg_L\text{-}P_L = 0$ in the CFEs of the states of *Chiapas, Jalisco* and *Michoacán* (p-value <0.05), *Durango, Puebla* and *Veracruz* (p-value <0.1), *Oaxaca* and *Quintana Roo* (p-value <0.001). When obtaining an estimated value greater than zero (Table 3), the interpretation is that these are EFCs that are not competitive and underuse input *L*, which means that the *MPV* of *L* is higher than the market price of resource *L*. For Model III, Ho is rejected: $Pmg_L\text{-}P_L = 0$ in the CFEs located in the states of *Oaxaca* and *Quintana Roo* (*p*-value <0.05). In a similar way, Ho: $Pmg_K\text{-}P_K = 0$ is rejected for the CFEs located in *Chiapas* and *Oaxaca* (*p*-value <0.01).

Regarding the analysis of *MPV* for *VD* in Models II and III with data added at the national level, Ho is rejected: $Pmg_{VD}\text{-}P_{VD} = 0$ with a significance level of 0.1 % (*p*-value <0.001). Specifically, for Model II, Ho is rejected: $Pmg_{VD}\text{-}P_{VD} = 0$ for all states (*p*-value <0.001), except the State of Mexico and *Jalisco*, in which no statistical significance was obtained.

The CFEs located in the states of *Chiapas, Chihuahua, Durango, Michoacán, Oaxaca, Puebla, Quintana Roo* and *Veracruz* when obtaining an estimated value lower than zero (Table 3) it is interpreted an overuse of the *VD* input, which means that the MPV of *VD* is lower than the market price of the *VD* resource. For Model III, Ho is rejected: $Pmg_{VD}\text{-}P_{VD} = 0$ for the CFEs located in the states of *Chiapas, Chihuahua, Durango, State of Mexico, Jalisco, Michoacán, Oaxaca, Puebla, Quintana Roo* and *Veracruz* (p-value <0.001) therefore, such CFEs are not competitive in the use of the *VD* resource (Table 4).

The relationship of the *MPV* and the cost of the factor is useful to determine the competitive use of resources, although no statistical significance was found to determine that there is non-competitive use of input *L* and *K* at the national level for Models I and III, also for input K of Model II. This suggests that there is no evidence of the under or overuse of both inputs in the production process, consistent with the maximization of the company's income. This result contrasts with that obtained by Frey *et al.* (2019), who determined that CFEs are competitive in resource use and performance at scale.

The statistical results of variance of the aggregated data and at the state level indicate that they are not significant. However, when comparing the aggregated data by state for model II, it was observed that *Chiapas, Jalisco* and *Michoacán* maintain the significance in the use of L at 5 % (*p* -value <0.5); while *Durango, Pu*ebla and *Veracruz* increase the level of significance to 1% (p-value <0.1) and *Oaxaca* and *Quintana Roo* to 0.1 % (*p*-value <0.001). The State of Mexico and *Jalisco* in particular do not record statistical significance in the analysis of *MPV* for *VD* (*p*-value> 0.05). The other states keep significance at 0.1 % (*p*-value <0.001) in a similar way as for the aggregated data. In Model III, only *Oaxaca* and *Quintana Roo* preserve significance at 5 % (*p*-value <0.05) in the *MPV* analysis for *L*. Contrary to the statistical results of the aggregated data, *Chiapas* and *Oaxaca* registered significance in the MPV analysis for *K* of 1 % (*p*-value <0.01); all the states are significant at 0.1 % (*p*-value <0.001) in the analysis of the MPV for the *VD* variable.

This behavior may be due to the wide dispersion in the values of the variables as a result of grouping the CFEs by state. For example, for *Chihuahua*, the annual *Q* value was: maximum = 4 709.88, minimum = 94.89 and mean = 2 392 Mpt year^{-1}; which is noticeably higher than the production in *Puebla* whose annual *Q* value was: maximum = 1 332.02, minimum = 402.70 and average = 771.051 Mpt year^{-1}. While for the 35 CFEs, *Q* was: maximum = 6 952 380, minimum = 90 956 and mean = 1 613 229 Mpt year^{-1}.

The hypothesis test Ho: $\beta_k + \beta_L = 1$ to determine non-constant returns to scale for inputs *L* and *K* and the results of the elasticities of the factors of production *L* and *K*, reflect that no model has constant returns to scale (Statistical F_1 in Table 1). In fact, for Model I an increasing yield to scale was obtained ($\beta_L + \beta_K < 1$); however, it decreases when adding continuous variables (*VD*, *CA*, *CM*, *CI*, *PO* and *PTD*) and nominal (*S*, *CERT* and *FL*) that affect productivity in Models II and III, respectively, so the returns are decreasing to scale for ($\beta_L + \beta_K < 1$), which means that, on average, CFEs may be operating under diminishing returns to scale in the short term, a trend similar to that described by Niquidet and Nelson (2010).

In this study there was high variability of the information of the CFEs analyzed, similar to that mentioned by Cubbage *et al.* (2015b); the only variables with little variability between companies were *CA* ($\mu = 0.518$, $\sigma = 0.051$) and *CM* ($\mu = 0.062$, $\sigma = 0.083$).

It is possible that the said variability between companies associated with *CI*, *CO*, *PO*, *PTD*, *CERT* influenced so that they had no impact on productivity. For example, the variable *CA* in Model II had no effect on production; the only continuous variable with an effect on productivity was *VD*, which is close to that obtained by Frey *et al.* (2019) for the variable total inventory of pine and oyamel wood to be used in the CFEs in Mexico.

It must be noted that government support through subsidies and forest certification had no effect on production, which coincides with the results obtained by Frey *et al.* (2019) for harvested volume. Although the information of the present study had high variability, the goodness of fit was good for the models, since it fluctuated between 81.60 and 84.60 %.

Conclusions

The Cobb-Douglas model as a particular expression of the production function is useful for constructing economic models that represent production, such as sawn wood in physical units. The economic models developed I, II and III can help define policies to promote the timber industry through the factors with the greatest impact, such as Labor, Capital and Available volume of wood.

It was determined that there is no competitive use of *L*, *K* and *VD* resources for the 35 CFEs analyzed and located in 10 of the Mexican states.

The *VD* and *FL* variables (*FL1*, *FL2* and *FL3*) had an effect on productivity for Models II and III, respectively. The CFEs formed as private companies and social companies provide 118 % and 44 % of the production, respectively. The legal figure of *ejido* contributes only 30 % in production.

The production functions generated are homogeneous of degree n> 1 with increasing returns to scale for Model I and homogeneous of degree n <1 with decreasing returns to scale for Models II and III.

The continuous variables *CA*, *CM*, *CI*, *PO* and *PTD* and nominal (*S*, *CERT*) had no effect on productivity. Although the sawing coefficient and installed capacity are related to the technological level of the industry, they did not contribute to increasing productivity. The wood classification variable is more of a strategy to increase the value of wood with little practical effect. The operational positions for women and positions for women in decision-making that are relative to the gender quota, did not affect productivity either; however, in investment projects supported by the World Bank and Conafor those that comply with the certification of good forest management and the gender quota are privileged.

It was not possible to identify the effect of subsidies integrated into a single concept on production because a short period of time (3 years) was analyzed and direct and indirect supports take longer to mature.

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Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Edgar Arturo Sánchez Moreno: research design, information collection and description, information processing, writing of the document; José María Salas González: support in the description of information and analysis of results; Sergio Pérez Elizalde: contribution to the methodology and statistical models, analysis of results; Marcos Portillo Vásquez: support in the selection of production, cost and income functions; José Luis Romo Lozano: support in the analysis of information on prices of products and supplies and writing of the document.

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