Technical efficiency in linkage of small farms to industrial supply chains: a Stochastic Frontier Analysis in Colombia

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Abstract

Agricultural policies in developing countries serve to promote the linkage of small holders to supply chains. To what extent does linkage to industrial supply chains increase efficiency in agricultural production among smallholders? We used data from the National Agricultural Census in Colombia in a stochastic frontier analysis. Selection bias was corrected using propensity score matching techniques, and parameters were estimated using probit models. We found that smallholders describe higher efficiency in self-consumption managing than linking production to supply chains because of constrictions in land tenure managing, crop land, and capital. Results help to understand the challenges smallholders have to face to be linked to supply chains. Policymakers should promote producers' associations in order to seek higher efficiency.

Keywords: Supply Chain; Efficiency; Productivity; Agricultural Production; Smallholders; Agro-Industrial production; Econometrics, Economics.

1. Introduction

Small farmers are vulnerable to economic shocks. Land-constrained farmers in developing economies tackle poverty with scarcity of resources. Low productivity in agricultural units affects producers' profitability. Price volatility in global markets leads to short-term uncertainties in agricultural production. The cost of inputs is high, while the price of output is often at the risk of approaching production cost limits. Therefore, small agricultural producers in developing economies need to improve their efficiency in the use of inputs to maximize production and achieve higher productivity. Linkages to the industrial supply chain has been proposed by scholars and policymakers as an alternative to increase productivity among smallholders in developing economies. To what extend does linkage to industrial supply chain increase efficiency in agricultural production among smallholders?

Agricultural producers need know-how and strategies to increase productivity through economic and environmental changes that challenge the agricultural sector. Otherwise, the management of the productive units will remain intuitive. Our study highlights the main challenges faced by smallholders in linking agricultural production to the industrial supply chain. Furthermore, our research provides inputs for dialogue with the scientific community and policymakers to design strategies and policies oriented to make the linkage of smallholders to vertical chains more suitable, increasing their technical efficiency.

There are two main methods to analyze efficiency (Koengkan et al, 2022): Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The literature provides advantages of each method, according to the research approach (Kazemzadeh et al, 2022; Wollni & Brummer, 2012). We use SFA considering that our focus is on the inefficiency of producers, and we apply Propensity Score Matching (PSM) to avoid bias in the comparison of technical efficiency between farms oriented to industrial supply chain, and farms oriented to self-consumption and local market.

Our focus on small farm is relevant because their efficiency in agricultural production leads to both economic and social effects. Productivity of small agricultural producers in developing countries is a leverage which contributes to moving them away from poverty.

We used data from the National Census in Agricultural Sector, of the National Statistic Agency (Dane, 2016). We framed our analysis in Pereira, which is a traditional agricultural region in Colombia. Small farmers in Pereira (Colombia) represent a reference for smallholders in developing countries, which experienced a critical stage of productivity during the coffee price crisis, and are now facing the involvement of vertical chains as alternatives to compete in the global market. Local producers faced a coffee price crisis at the end of the 20th century, leading to land-use change. Traditional growers sought alternative income through different agricultural activities like plantain, sugar cane, mulberry and dairy products.

Growers and the government need to increase production efficiency and assess strategies according to agricultural performance. Linking agricultural production to the industrial supply chain is an alternative that has led to significant changes among agricultural producers. Since the coffee crisis affected the profitability of agricultural units, it was necessary to increase productivity through the efficient use of inputs, mitigation of the impact on natural resources, promotion of food security, and improvement of life standards among smallholders.

Our research provides a main contribution to shaping the strategy of linking agricultural producers to industrial supply chains. According to the literature, it is expected that linkage to supply chains increases efficiency (Karantininis et al., 2010; Biggeri et al, 2018; Bagchi, Mishra & Behera, 2021). On the other hand, our results show that small farms are more efficient if they orient their production to self-consumption or local market, rather than to the industrial supply chain. Small farms in developing economies use to face further challenges like scarcity of resources and lack of managerial education. Involvement in supply chains need a period of adaptation and training for management of clusters, besides the traditional agricultural production. Our main findings contribute to spot the gaps in the effort of small farmers to be linked to supply chains. Nevertheless, involvement in supply chains is not enough by itself; rather, small farmers need to be supported by specific programs launched by policymakers, accelerating the adaptation period to supply chain management, and providing access to financial schemes oriented to compensate the lack of resources, which turns traditional agricultural production into a productive unit among a supply chain strategy.

2. Literature Review

Productivity is the rate of output out of inputs (Coelli, Rao, O'Donnell & Battese, 2005). Factor endowment refers to the use of inputs that lead to output. There are several classifications of production factors. Some authors include land, capital assets, administrative capacity, infrastructure, labor, and financial capital (Ragland et al., 2015). Other academics have identified three productive factors: land, labor, and capital (Feenstra, 2016). Enterprises belonging to the industrial sector are capital-intensive, whereas agricultural productive units are land-intensive (Fugile & Wang, 2012). Human capital is another critical issue in agricultural production (Nowak & Kijek, 2016). Lower education levels among workers could have a negative impact on production efficiency. Therefore, capital and land are key inputs in the linkage between the agricultural and industrial sectors in agribusiness systems.

Linkages to the industrial supply chain are expected to generate added value in agricultural production. Karantininis et al. (2010) studied 444 productive units in Denmark's agribusiness sector to identify the added value generated by industrial chains. They concluded that the vertical chain in agribusiness creates a more suitable differentiation through innovation. For example, avocados can be sold directly as food in trade, without going through the industrial sector. Alternatively, avocado can be transformed into pharmaceutical products, which requires industrial transformation and added value for specific uses.

Industrial linkages qualify for product attributes. Quality improvement is an additional benefit of productivity increase within the industrial supply chain. Zhao, Wang, and Pal (2020) described a multiplier effect on the formalization of agricultural production from integration into industrial chains, based on the analysis of 162 agricultural producers in China. In contrast, the direct sales of agricultural products face high uncertainty due to volatility in the prices of primary products. In addition, there is uncertainty in trade according to changes in the relationship between supply and demand. On the other hand, the industrial chain reduces economic risk by formalizing the relationship between agricultural producers and industrial firms through transactions such as prices, quantities, frequencies, weights, and so on.

Linkage of small farmers in supply chains could lead to economic benefits in developing economies. Bagchi, Mishra and Behera (2021) found that collectivization and diversified production chains strengthen market linkages for agricultural producers in India. A comparative analysis in European developing countries from Rivera et al (2020) recognized a significant role of small producers in regional food production, driven by the structure of specific supply chains and market linkages, and the abundance of small producers in the agricultural landscape.

Involving land-poor farmers in industrial supply chain has been regarded as having a positive effect on productivity (Biggeri et al, 2018). The Agricultural Value Chains Project in Oromia (AVCPO) was launched in the Bale zone in Ethiopia; this project resulted in an improvement in the livelihoods of small farmers. However, further evidence is needed to determine the effects of linking small producers located in areas without specific programs oriented to this goal, as in the case of AVCPO. Furthermore, linking small farmers to supply chains face some uncertainties, because land-constraint farmers need more time to get adapted to the arrangements of supply chains, and they would need to develop access to markets and new management skills (Fischer & Quaim, 2012). The timing sequences according to the contract affects the performance of the supply chain (Tu, Sun, Huang, 2022). More specific research is needed to compare efficiency between traditional production and linking production to supply chain among small farm holders (Bagchi et al, 2021).

The combination of inputs oriented to direct food supply or to the provision of raw materials represents an opportunity cost for agricultural units managers. However, it is difficult for agricultural producers to have a clear understanding of productivity indicators because of the lack of data on developing countries. One of the main components of productivity is technical efficiency, which refers to the relationship between output within a production unit and the maximization of the use of inputs (Coelli & Fleming, 2004). Technical efficiency considers the boundaries of possibilities in the use of factor endowments.

Jiménez et al. (2018) used stochastic frontier analysis to study the growth of agricultural productivity in Colombia between 1975 and 2013. They pointed out that productivity is a major factor in agricultural activity in Colombia. Productivity in the agricultural sector grew over the years studied, with an annual average of 0.8% to 1.3%. They did not focus on linkages in the industrial supply chain. Instead, they interpreted productivity growth from institutional circumstances such as the peace process, which allows access to inputs. In addition, they analyzed several activities within the agricultural sector, not only agricultural crops. They concluded that productivity in Colombia is mainly driven by the livestock sector and poultry and livestock production activities.

The combination of productive factors determines efficiency within the supply chain. Spinelli et al. (2020) stated that the difference in productivity, according to the articulation of inputs, could vary between 25% and 50%. There is higher productivity as uncertainty is reduced with access to information within the decision-making process.

Gurnaschelli et al. (2020) analyzed the supply chain in agricultural production through stochastic methods, according to the destination of production. The authors conducted research on dairy production oriented to cheese, yogurt, milk powder, and pasteurization of milk (UHT). They concluded that changes in factor endowments influence productivity by 21.1 percent.

3. Data and Methods

The object of our analysis is the efficiency of agricultural producers, according to their linkage to industrial supply chain. The development of the competition in the global economy pushes producers to manage a more efficient use of resources (Koengkan et al, 2022). Agricultural producers face the alternatives of traditional agri-food production, mainly for self-consumption in small farms, or linking their production into an agribusiness chain. Producers and policy makers need to consider which thread provide higher efficiency.

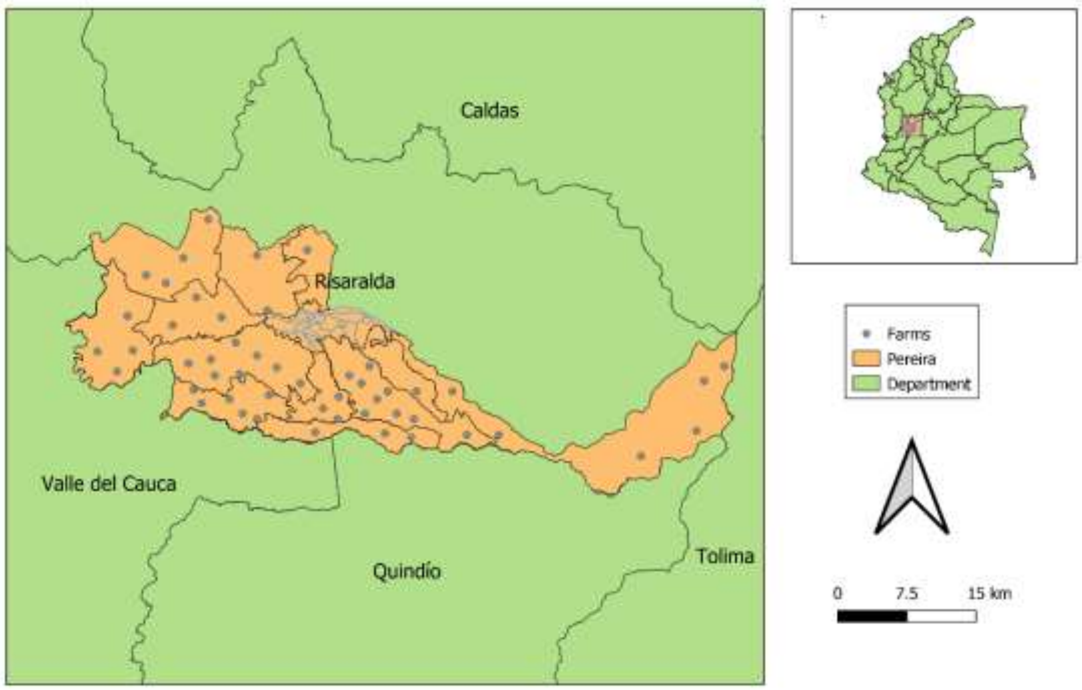

***Fig.1.**. Location of farms in Pereira, Colombia*

Cross-sectional data were based on microdata from the Third Agricultural National Census published by the National Department of Statistics (Dane) in 2016 and adjusted in 2017. We focused on the area of Pereira at the Department of Risaralda, which is a traditional region for agricultural production in Colombia. Figure 1 shows the location of farms in Pereira. The period of data coincides with the thread in global economy toward increasing efficiency, and the census is an opportunity to know the production efficiency of agricultural producers. The Third Agricultural National Census reported that approximately 81% of the land belongs to 1% of the population. Further, around 80% of growers work on less than five hectares of land (Dane, 2016). Inequality in land tenure and agricultural land fragmentation describe the high dispersion of data. Therefore, we applied a random sampling method to analyze a more consistent group of observations. The sample size was estimated according to the classic formula of Cochran (1977) for groups with a population higher than 100.000 in Equation 1. The confidence level was 95%, e was the margin of error of 5%, p was the estimated affirmative answer, q was the estimated negative answer. According to Equation 1, the minimum estimated sample size was 384. We took 477 farms that reported data for the variables used in this analysis, which are defined in Table 1.

$$Sample = \frac{z^2 * p * q}{e^2} \qquad (1)$$

Tab. 1. *Definition of Variables*

Variable	Parameter	Unit	Definition
Yield		Ton/He.	Production of crops
Crop Land	β_1	Hectares	Land for crop production
Labor	β_2	Hectares	Number of workers in the farm
Capital	β_3	Machineries	Number of machineries in the farm
Supply Chain	β_{CHAIN}	Dummy	1 or 0; 1 if farm is linked to a commodity chain.
Education	α_1	Dummy	1 to 9. 1 if education level is elementary school and 9 if is university level
Membership	α_2	Dummy	1 to 0. 1 if producers are affiliated to association of producers
Total Land	α_3	Hectares	Area of the farm
Age	α_4	Years	Age of grower

The variables in our study are defined in Table 1. We consider crop land, capital and labor within our factors of productions because the traditional literature uses these variables like inputs for efficiency analysis (Wollni & Brummer, 2012). Further, we use the participation of farm within supply chain like criteria to differentiate the destination of production. Finally, we consider some management variables like education and membership to association of producers, and total land of farm, identifying the contextual features of producers in relation to the scale of farming system.

An estimation of both samples of farms linked to industrial supply chains and farms without linkages could describe selection bias. The propensity score matching (PSM) method allows us to match these groups based on controlling variables to avoid bias. Therefore, we ensured similar conditions in both the treatment and control groups. Table 2 presents the descriptive statistics of the unmatched and matched samples.

Tab. 2. *Descriptive statistics for unmatched and matched sample*

	Pooled group		Supply Chain		No Supply Chain	
Variables	**MEAN**	**SD**	**MEAN**	**SD**	**MEAN**	**SD**
Unmatched						
Yield	6.704	6.177	5.674	6.043	7.514	6.172
β_1	4.246	7.427	5.241	9.230	3.463	5.510
β_2	3.709	21.972	5.419	32.768	2.363	4.013
β_3	1.818	3.018	1.405	1.703	2.142	3.711
β_{CHAIN}	0.441	0.496				
α_1	1.918	2.523	2.152	2.656	1.734	2.403
α_2	0.075	0.264	0.080	0.273	0.071	0.257
α_3	9.202	25	11.233	16.178	7.605	29.514
α_4	52.380	2.523	52.310	13.997	52.420	14.343
N	477		210		267	
Matched						
Yield	6.670	6.177	5.674	6.043	7.666	6.349
β_1	4.565	7.427	5.241	9.230	3.888	6.103
β_2	3.998	21.972	5.419	32.768	2.576	4.478
β_3	1.698	3.017	1.405	1.703	1.990	1.971
β_{CHAIN}	0.500	0.496				
α_1	2.174	2.523	2.152	2.656	2.195	2.515
α_2	0.085	0.264	0.080	0.273	0.090	0.287
α_3	8.640	24.596	11.233	16.178	6.047	13.537
α_4	52.380	14.177	52.310	13.997	52.440	14.143
N	420		210		210	

Koengkan et al (2022) explains that there are two main methods two analyze efficiency: the non-parametric method Data Envelopment Analysis (DEA) based on the efficiency of Decision-Making Units and no conditional on a function or technology specification, and the parametric method Stochastic Frontier Analysis (SFA), focused on the inefficiency of producers. The paper compared DEA and SFA measuring efficiency performance of 14 Latin American and Caribbean countries, based on energy, labor and capital, finding similar results in the overall sample, but with some differences in the rankings of countries. Kazemzadeh et al (2022) use Data Envelopment Analysis (DEA) to calculate energy efficiency in developing economies based on linear programming and distance performance, and combine DEA with a slack-based model (SBM), which belongs to a non-radial distance function model that allows to prevent the deviation of radial or oriented models, estimating performance within the assumption that producing more output than less input and poor output is a crucial factor in efficiency analysis. Wollni & Brummer (2012) used SFA to determine technical efficiency of specialty and conventional coffee farmers in Costa Rica, measuring the compound error term with the degree of efficiency of each producer and the random fluctuations based on a natural distribution.

We use SFA considering that the focus of our research was on the efficiency of producers. First, we calculated the probit model using Equation 2. The probit function is denoted by $\Phi(\ \ )$, and α includes parameters such as education, membership to cooperatives or associations of producers, total farm land, and age.

$$y = \Phi(\alpha + \mathcal{E}) \qquad (2)$$

Second, stochastic frontier analysis is applied to determine the production function, using the Cobb-Douglas functional form in Equation 3 (González-Flórez, Bravo-Ureta, Solís & Winters, 2014). The model explains the relationship between the independent variables, denoted as crop land, labor and capital, and the intervening variable (supply chain), which corresponds to the dummy variable T, that takes the value of T = 0, if the productive unit i does not face its production to be sold to industrial chain, and T = 1, if the production is destined like raw material of the industrial sector. Finally, the dependent variable (yield) was measured based on the number of tons produced per hectare.

$$lnYi = \beta 0 + \sum_{j=1}^{4} \beta ln\chi_{ji} + v_i - u_{i(3)}$$

4. Results

We estimated the technical efficiency for the pooled sample of 477 farms, considering whether they are linked to the industrial supply chain. Table 3 presents the efficiency of agricultural production for the unmatched and matched samples according to the Cobb-Douglas production function. Crop land provides the highest contribution to the volume of production and is highly significant across the models. In every case, the partial production elasticities are less than 1, indicating a decreasing return to scale. This result is consistent with the findings of Bravo-Ureta (2014) for smallholders, such as most observations in our sample. According to descriptive statistics in Table 2, the mean of crop land is between 3.5 and 7.5 hectares across the subsamples.

Tab. 3. Efficiency in agricultural production – Unmatched and Matched samples

Variables	Pooled		Supply Chain		No Supply Chain	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Unmatched						
Constant	2.879***	0.082	2.795***	0.126	2.770***	0.093
β_1	0.128***	0.037	0.157**	0.058	0.127**	0.041
β_2	-0.120*	0.054	-0.175*	0.759	-0.033	0.083
β_3	0.147*	0.060	0.187*	0.089	0.087	0.083
β_{CHAIN}	-0.150.	0.080				
RTS	0.155		0.169		0.181	
N	477		210		267	
Matched						
Constant	2.885***	0.888	2.795***	0.126	2.777***	0.108
β_1	0.129***	0.039	0.157**	0.058	0.126**	0.048
β_2	-0.128*	0.055	-0.175*	0.075	-0.065	0.087
β_3	0.198**	0.604	0.187*	0.089	0.180.	0.091
β_{CHAIN}	-0.163*	0.082				
RTS	0.199		0.519		0.241	
N	420		210		210	

*** p < 0.000; ***p < 0.001; * p < 0.05; . p < 0.1

Labor is significant and negative for farms oriented to the industrial supply chain in the matched and unmatched samples, considering that marginal production decreases if the number of workers overwhelms the nameplate capacity of the farm. This result is consistent with Nowak and Kijek (2016), who found that labor productivity is lower when workers have low education levels. Table 2 shows that the education level is classified around two in a range between 1 (elementary school) and 7 (undergraduate program). Small farms do not need further labor because more workers can decrease production efficiency if they do not have enough land to work. Labor is not significant in the case of farms without links to industrial supply chains. Small farms without industrial linkages are oriented to self-consumption and do not need to increase marginal inputs of labor within production.

Table 3 shows that capital is significant in the pooled sample for both the unmatched and matched models. The same results were obtained for farms oriented to the industrial supply chain. Rather, capital is not significant in either the unmatched or matched model for farms without linkages. Farms involved in the industrial supply chain need higher technification and more use of technologies, special infrastructure, machinery, and equipment. This is an attribute of farms that meet the requirements of their industrial partners.

The effect of correcting bias is estimated in Table 4, where the null hypothesis is rejected because not all the coefficients are zero. Both probit models in the unmatched and matched samples were incompatible. Probit in the unmatched sample describes statistical significance at the 10% level in education. Rather, the total land of farms is described as the main factor in the probit model for the matched sample at 0,1% significance. The difference between the models is explained by the fact that the unmatched sample includes a higher dispersion among observations. PSM adjusts the levels of variables among the matched farms and reduces the bias in the comparison. Overall, farmland is a significant input for farms in terms of production.

Tab. 4. *Parameter estimates for probit selection*

	Unmatched		Matched	
Parameter	Coefficient	S.E	Coefficient	S.E
α_1	0.041.	0.022	0.001	0.024
α_2	0.058	0.218	-0.111	0.221
α_3	0.003	0.002	0.014**	0.005
α_4	-0.001	0.004	0.001	0.004

*** p < 0.000; ***p < 0.001; * p < 0.05; . p < 0.1

The technical efficiency scores for both unmatched and matched samples are presented in Table 5. The scores were similar in both the subsamples. There is higher efficiency in farms without linkages to industrial commodity supply (40,8%) than in farms involved in industrial supply chain (33,6%). Smallholders have greater control of inputs according to their self-consumption needs. However, agricultural production for industrial purposes requires more land to ensure higher marginal production to behave like economies of scale.

Tab. 5. *Technical Efficiency Scores*

	Unmatched Mean	**Matched Mean**
Pooled	0.369	0.365
Supply Chain	0.336	0.336
No Supply Chain	0.408	0.402

5. Discussion

Linking agricultural production to industrial commodities is a valuable step toward increasing living standards in rural populations. However, our results in the case of Pereira in Colombia did not follow the evidence from traditional literature (Bagchi, Mishra & Behera, 2021). In contrast, our findings show that small farmers are focused on self-consumption and does not have enough resources to be involve in supply chain. Therefore, farms without linkage to industrial supply chain are more efficient. Results are consistent with Tu, Sun & Huang (2022), which considers that land-constrained farmers face some barriers to be involved in supply chains due to timing for development of linkage and contract arrangements. Agricultural communities which are not targeted by specific supply chains programs should move by themselves toward industrial linkage without the managerial knowledge (Biggeri et al, 2018).

The linking of small farms to the industrial supply chain needs to be complemented with more incentives, leading small farmers to move from self-consumption to complex relationships within the commodity chain. For instance, small farmers need more control over the cost of inputs and protection from foreign competitors within the negotiation of Free Trade Agreements. Specific funding programs for small farms within supply chains should be launched, accelerating their adaptation period, and turning traditional agricultural production into productive units involved in commodities chains. Furthermore, small producers could be supported if they find new destinations for their products in global trade. Finally, investments in research and development (R&D) would strengthen the industrialization of the agricultural economy.

This particular case study focuses on small farmers in Pereira (Colombia). According to Dane (2016) around 80% of farmers do not have high education level. Further, 80% of farmers are generally older than 50 years old, and they own less than five hectares. Just 1% of population own 81% of land for agriculture. This description draws further barriers to be tackled in addition to industrial linkages with the supply chain.

5. Conclusions and policy implications

Farms without linkages to industrial supply chains describe higher technical efficiency (40,8%) than those involved in the industrial supply chain (33,6%). Smallholders are more suitable for managing inputs according to their needs for self-consumption. Furthermore, total land is a significant factor to be considered for linking to the industrial supply chain. Therefore, small farms could increase efficiency through producers' cooperatives, sharing resources and taking advantage of industrial linkages. In addition, farms linked to industrial supply chains describe a higher use of capital, such as machinery, equipment, and infrastructure. Higher land use could allow them to use capital more efficiently.

Crop land is the main factor that increases farm efficiency, according to our estimated models. Whether farms are oriented to the industrial supply chain or not, crop land remains the key input for improving efficiency in agricultural production.

The linkage to the industrial supply chain is a milestone in the development of the agricultural economy. However, this effort should be complemented with further strategies such as diversification of production, protection of small farmers from foreign competitors, diversification in export destinations, and investment in R&D.

Technical efficiency can be estimated according to the participation of farms in horizontal linkages, asking about the effect of long-term cooperative agreements between small producers. Several farms could increase their crop land under the same management oriented to industrial supply chains. Therefore, more complex linkages, such as clusters, can be evaluated to analyze the effects on efficiency in agricultural production.

Results provide inputs with policy implications, regarding the need to encourage cooperatives and association of agricultural producers. Small agricultural producers face constrictions to achieve efficiency, and their production in small farms focuses on self-consumption, neglecting the opportunity of standardizing production within an industrial supply chain. Further, associations of agricultural producers allow them to aggregate their inputs into a bigger production unit, overcoming the limitations caused by a small-scale production process, which results in higher efficiency.

6. Limitations and future recommendation

Results have some limitations when the data factor is taken into consideration. This research followed a cross-sectional analysis because the most recent national agricultural census in Colombia was conducted in 2016. The previous data were collected 40 years before the recent census; therefore, it was not possible to analyze panel data to describe the time series or evolution of efficiency within the sample of farms. The performance of the producers could not be compared due to the long period of time between both data. Further research may be conducted by collecting data in-situ, and building panel data through time series analysis to review changes in inefficiency of producers during a longer period.
Another limitation was the outcome. The national census asked for volume of production rather than income. These units in the dependent variables avoid estimating the efficiency of resources in economic terms.
Further research could also consider the possibility to analyze horizontal linkage. The present paper focused on vertical linkage, represented by the destination of agricultural production within the industrial supply chain. However, the opportunities to increase efficiency in horizontal linkage could be explored through cooperatives and cooperation among agricultural producers, sharing their inputs to reduce costs within the production process.

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