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Land Ownership and Technical Efficiency of Sorghum Production in Burkina Faso: A Stochastic Meta-frontier Approach

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We estimate and compare technical efficiency (TE), technology gap ratio (TGR), and meta-technical efficiency (MTE) of sorghum production between three groups of plots which have been classified on the basis of the type of land property rights held by farmers (formal land rights, customary land rights, and no land rights). Nationally representative household data collected in 2011 in rural Burkina Faso are analyzed. The stochastic meta-frontier approach is followed to address the heterogeneity of the technologies used by sorghum farmers. The TE and MTE are estimated at 69% and 51.96%, respectively. It is found that the group of plots held with formal land rights has the higher MTE and TGR, implying that farmers use the best technology on these plots where they are more efficient. This evidence may highlight the positive effect of land property rights security in the adoption of better farm management practices stimulating production efficiency. The results imply that sorghum farmers have the possibility of increasing their level of production by 31% with the same resources. We argue that securing land property rights by a well undertaken formalization process is one of the factors helping to stimulate this possibility.

Key words: Burkina Faso, Formalization of Land Rights, Stochastic Meta-frontier Approach, Technical Efficiency

Cereal production plays a central role in Burkina Faso agriculture which is essentially subsistence based (Séogo and Zahonogo, 2019). The consumption of cereal products in this country represents more than 60% of the population's caloric needs and the share of sorghum in meeting these caloric needs is estimated at an average of 19% (Ministère de l'Agriculture et de la Sécurité Alimentaire, 2012). Sorghum is also used in the production of alcoholic beverages such as local beer *"dolo"* (traditional low-alcohol beer) and as food for animals. With an annual average harvest of more than 1,450,000 tons, sorghum is the most produced cereal crop in Burkina Faso and is grown in all regions by more than 71% of farm households in the rainy season. In 2010, the national production of sorghum was estimated at about 1,460,000 tons, representing 3% of the entire world production, making Burkina Faso the fourth largest producer in Africa (Food and Agriculture Organization (FAO), 2013). Sorghum is largely exported to Niger and occasionally to other countries such as Chad, Ghana, and Nigeria.

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Despite this major contribution of sorghum cultivation to the economy, there has been a dramatic shift in sorghum production over time. In addition to climatic factors that sometimes cause weak agricultural performance, fertilization rates are poor and technology adoption remains low. Indeed, the production system is extensive and few farmers apply fertilizers (less than 2% of cereal growers use fertilizers) or improved technologies (FAO, 2013). Farmers' technical inefficiencies may also be a factor underpinning production. Indeed, it is argued that low agricultural investment and inefficient use of resources are constraints to both achieving an optimal level of production and generating significant income for households relying on agriculture as their main subsistence activity (Brümmer, 2006; Zahonogo, 2016). Sustained growth in productivity requires enhancing producers' efficiencies in resource use (Adeguelou et al., 2018).

Since land is the main resource in agriculture, land property rights are necessary to ensure not only the security of productive investments in land, but also to induce a rational use of input factors and a sustainable exploitation of land. Secure and transferable land rights are expected to provide access to credit, induce efficient use of agricultural inputs, and increase farm productivity (Besley, 1995; Feng, 2008; Donkor and Owusu, 2014). The empirical studies addressing the effect of land rights on production efficiency show that, in general, when the land tenure system provides secure access to land, it leads to a high level of work and land management efforts, increasing the efficiency of farm households (Feder and Feeny, 1991; Michler and Shively, 2015). This paper, therefore, investigates how efficiently is the use of resources devoted by different landowner groups to sorghum production.

In Burkina Faso, issues related to land tenure insecurity are identified as factors that hamper the achievement of the potential level of agricultural production which can sustainably ensure farm households' food security (Linkow, 2016). The customary land tenure system which is dominant is increasingly incapable of providing land tenure security because competition for land is becoming more intense (Paré et al., 2008; Séogo and Zahonogo, 2019). Burkina Faso authorities undertook a land reform in 2009 (through Law No. 34/AN) to guarantee the security of private land investments in rural areas. While recognizing customary land ownership, the new land law aims at promoting agricultural entrepreneurship by providing opportunities for national and non-national economic actors to privately appropriate land for profitable investments in the agricultural sector. Since this reform, the country land tenure system is characterized by the coexistence of both customary and modern land governance. Overall, three groups of landowners coexist: customary owners who have generally inherited their land, formal owners who have formal rights, and non-owners who negotiate with customary landowners for use of the land. The analysis aims at discovering which group uses the best technology, which group is the most efficient, and what are the factors explaining the technical efficiency of sorghum production.

Previous studies have shown that cereal farmers in Burkina Faso are technically inefficient and that many socio-economic factors could explain their inefficiencies (Wouterse, 2008; Combary, 2016). However, studies taking into account the heterogeneity of technologies across different land tenure groups in the country are non-existent to our knowledge. Our research fills this gap and contributes to enriching the literature on the subject. We follow the meta-frontier approach which is more appropriate in solving the problem of technology heterogeneity. In this study, it is found that the three landowner groups have specific agricultural characteristics and practices, implying that the production technologies are not homogeneous. The traditional method of pooling all observations in the estimation method may lead to fruitless results. The stochastic meta-frontier approach is adapted and provides very conclusive results.

The rest of the paper is structured as follows. After a brief description of the Burkina Faso land tenure system, the theoretical model is presented, followed by the empirical model, and the data. The results section presents and discusses the econometric results, and the paper concludes with implications for economic policy.

A Brief Description of Burkina Faso Land Tenure System

After independence in 1960, land governance in Burkina Faso was primarily left to customary institutions. In 1984, the country's modern statutory system (the law "*Réorganisation Agraire et Foncière*") was introduced to develop a private property rights regime for land. The law was amended in 1991 and 1996, and vested all land in the state, regardless of customary tenure status (Hughes, 2014). The 1984 land tenure reform was criticized as it did not accommodate the complexity of the customary land tenure system, on one hand, and was not likely to bring about development of agribusiness for profound transformation, on the other hand.

Following a long, transparent, and inclusive process, a new Rural Land Tenure Law was thus adopted in June 2009 to ensure equitable access to rural land; promote investments in agriculture, forestry, and pastoralism; reduce poverty in rural areas; and to promote sustainable management of natural resources (Hughes, 2014). The law recognizes customary land ownership by establishing a Rural Land Certificate of Possession (APFR) for those who aim at formalizing their customary ownership. The APFR provides recognition of existing customary individual and corporate land rights subject to the condition that they have been rigorously vetted and approved by the local community (Séogo and Zahonogo, 2019). To provide women, migrants, and agribusiness people with secure land rights, the law allows all stakeholders, without any discrimination related to gender or origin, to acquire land under full private ownership by following formal rules (see Hughes (2014) for more details on the process of getting formal rights).

In spite of authorities' efforts to modernize the land tenure system, the customary land administration system continues to dominate. The majority of the customary farmers are not attracted by any individual land rights and strongly believe that no one dares to encroach upon their rights inherited from their ancestors (Séogo and Zahonogo, 2019). A few people own formal land rights in rural areas.

In the current context of Burkina Faso, farmers can be classified in three groups according to the type of land rights they own: (i) the customary land rights owners, (ii) the formal land rights owners, and (iii) the non-owners of land rights. The customary land rights owners inherited their lands and represent more than 80% of farmers (Séogo and Zahonogo, 2019). They are indigenous people (men and the elderly) in the village who are the customary owners of land. Non-owners are women, migrants, and younger people in the family. They cannot own land in the customary system since the customary governance of land is only devoted to men and the elderly in the family (Swedish International Development Agency, 2004). Migrants are non-indigenous people who definitely moved from landless and less agro-climatically favored zones (especially the Sahelian and the Sudano-Sahelian zones) to settle in land abundant and high potential agricultural zones (especially the Sudanian zone). With land scarcity, internal migration was said to have become increasingly common (Linkow, 2016). Formal owners are rich, non-native people and agribusiness actors who aim at securing their land investments. After negotiating the land from local communities, they may undertake the entitlement process (Séogo and Zahonogo, 2019).

Theoretical Framework

Referring to the neoclassical theory, firms are rational and aim at maximizing their profits. They are generally considered to be fully efficient. Farrell (1957) showed that, in reality, this hypothesis of full efficiency is not always verified as some firms fail to produce a maximum output from a minimum level of inputs. Farrell (1957) then suggested that the production level of the most efficient firm be considered as a production frontier for all firms. The firms which are unable to achieve this level of production with the same quantities of factors are inefficient.

One of the main criticisms against Farrell's (1957) frontier approach is that the production frontier he defined was deterministic like in non-parametric methods; that is, any deviation from the frontier was explained by the technical inefficiency of production units. However, there are observable or unobservable factors that may explain these gaps to the frontier. For this reason, the stochastic frontier approach was introduced by some authors, namely Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977). This approach allows hypotheses testing and breaks down the gap (u_i) between the level of production achieved and the frontier into two components: the technical inefficiency (η_i) and the error term ($\emptyset_i$). Any deviation from the frontier is now explained by the technical inefficiency and a random term that captures random variations in production. Considering N production units using K inputs, the production frontier is expressed as:

$$(1) \qquad R_i = f(X_{ij}\ ;\ \beta)e^{(\emptyset_i - \eta_i)} \quad \emptyset_i - \eta_i = u_i \ \text{ and } \ i = 1, \dots N; j = 1, \dots . . K$$

where R_i is the output level of production unit i; X_{ij} a vector of inputs (j) used, and β a vector of parameters to be estimated.

$\emptyset_i$ is supposed to be independently and identically distributed as $N(\mu, \sigma_\emptyset^2)$ and η_i a non-negative stochastic variable. The variance (σ^2) of u_i is the sum of the variances of its two components: $\sigma^2 = \sigma_\emptyset^2 + \sigma_\eta^2$. Aigner, Lovell, and Schmidt (1977) showed that the value of $\gamma = \sigma_\eta^2/\sigma_u^2$ must lie between 0 and 1. The value 0 indicates that the deviations from the frontier are entirely due to noise, and the value 1 indicates that all deviations are due to the technical inefficiency.

The technical efficiency of production unit i (TE_i) is defined as the ratio between the observed output (R_i) and the output given by the frontier (R_i^*):

$$(2) \qquad TE_i = \frac{R_i}{R_i^*} = \frac{f(X_{ij}\ ;\beta)e^{(\emptyset_i - \eta_i)}}{f(X_{ij}\ ;\beta)e^{(\emptyset_i)}} = e^{(-\eta_i)}$$

The above reasoning is based on a fundamental assumption: the homogeneity of the production technology, which means that all production units have the same production technology. In a situation of heterogeneity of production technologies used by different groups, Battese, Rao, and O'Donnell (2004) and O'Donnell, Rao, and Battese (2008) argued that it is unjustifiable to compare the efficiency levels of production units by adopting the above stochastic frontier approach. The main reason is that each group has its own frontier and the frontier which is defined in the pooled method does not cover all the frontiers that are specific to each group. Estimating the efficiency of each group separately also does not allow such a comparison to be made since each group has a specific frontier that determines the level of efficiency achieved by each production unit in the group. Thus, they introduced their meta-frontier approach, a two-step method for defining a global frontier (meta-frontier) encompassing the frontiers which are specific to the groups. The first step uses the above stochastic frontier approach by estimating equation (2) for each group. The second step uses mathematical programming techniques to obtain the meta-frontier based on the results in the first step.

However, the method of Battese, Rao, and O'Donnell (2004) and O'Donnell, Rao, and Battese (2008) has two major weaknesses, according to Huang, Huang, and Liu (2014). Firstly, the programming method used in the second step provides results that have no statistical properties. Secondly, the estimation method does not isolate idiosyncratic effects since it does not take into account the differences associated with the production environment faced by each group. To address these issues, Huang, Huang, and Liu (2014) proposed a two-step method that uses the stochastic frontier approach throughout the process. The first step is to estimate the technical efficiencies of production units (i) of each group (h) as follows:

$$(3) \qquad TE_{ih} = \frac{R_{ih}}{R_{ih}^{*}} = \frac{f_h(X_{ij}\ ;\ \beta_h)e^{(\emptyset_{ih}-\eta_{ih})}}{f_h(X_{ij}\ ;\beta_h)e^{(\emptyset_{ih})}} = e^{(-\eta_{ih})}$$

where $f_h(X_{ij}\ ;\beta_h)$ is the frontier function of the group, R_{ih} is the observed output, and R_{ih}^{*} *is* the frontier output. The variables η_{ih} and $\emptyset_{ih}$ are, respectively, the technical inefficiency and the error term components.

The second step uses the production predictions of each unit in the three groups $\widehat{f_h}(X_{ij}\ ;\ \beta_h)$ to formulate the following equation:

$$(4) \qquad \widehat{f_h}(X_{ij}\ ;\ \beta_h) = f_M(X_{ij}\ ;\ \beta_M)e^{(\emptyset_i M-\eta_{iM})} \qquad h = 1 \dots H$$

where H is the number of groups, $f_M(X_{ij}\ ;\ \beta_M)$ is the meta-frontier function that takes into account all groups, $\emptyset_i M$ is the random and systematic error term, and η_{iM} is the random and not negative component measuring the technical inefficiency. The estimated individual technical efficiency in the meta-frontier function (MTE_{ih}) is a fraction of the estimated individual technical efficiency in each group (equation 6). This fraction, called "the technology gap ratio (TGR_{ih})," is the ratio between the frontier of group h and the meta-frontier:

$$(5) \qquad TGR_{ih} = \frac{R_{ih}}{R_{iM}} = \frac{f_h(X_{ij}\ ;\ \beta_h)}{f_M(X_{ij}\ ;\beta_M)} = e^{(-\eta_{iM})} \leq 1$$

The MTE_{ih} of the meta-frontier function (equation 4) then verifies the following equality:

$$(6) \qquad MTE_{ih} = TGR_{ih} \times TE_{ih}$$

To sum up, the approach consists in using first the stochastic frontier method to estimate the technical efficiency of production units in each group, then predicting outputs in order to use them as a dependent variable in the second step to estimate the meta-frontier function (by using, again, the stochastic frontier method). The technical efficiency in the second step is the product of the efficiency estimated in the first step and the technology gap ratio which is always less than or equal to the unit.

Regarding variables explaining the technical inefficiency, Huang, Huang, and Liu (2014) distinguish two types of environmental variables: the group-specific variables used in the first step (equation 7) and the variables related to the environment of production units, i.e. those which are not directly related to production units, but which are likely to affect their efficiency. These variables are included in the second step (equation 9).

The reason to use two sets of variables is to purge the so-derived technology gap ratio measures from the influence of random shocks and errors of group-specific frontier estimations. Moreover, it allows one to identify the sources of variation in group-specific technology gap ratios with environmental variables beyond the control of production units. By using panel data of the hotel industry in Taiwan, Huang, Huang, and Liu (2014) verified that the omission of environmental variables from the second-step estimation causes an underestimation of the technology gap ratios.

Empirical Model

Model Specification in the First Step

The advantage of the stochastic frontier production approach is that it allows a simultaneous estimation of the inefficiency and its determinants. This estimation method is recommended since it provides consistent results (Coelli, 1995). The translog and the Cobb Douglas production functions are mostly used in the literature. In this analysis, we use the translog form, which is more flexible compared to the Cobb Douglas form. Assuming that the level of production is a function of the production factors used, the model is specified in the first step for each land property rights group h as follows:

$$(7) \quad lnR_{ih} = \beta_{0h} + \sum_{j=1}^{4} \beta_{jh} X_{ijh} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \beta_{jkh} X_{ijh} X_{ikh} + (\emptyset_{ih} - \eta_{ih}) \quad h = 1,2,3$$

where R_{ih} records the quantity of sorghum harvested on the plot, X_{i1h} the quantity of chemical fertilizer, X_{i2h} the quantity of organic manure, X_{i3h} the quantity of labor, and X_{i4h} the area of the plot. $\beta_{0h}, \beta_{1h}, \ldots \beta_{34h}$ are the parameters to be estimated, $\emptyset_{ih}$ the error term, and η_{ih} is the technical inefficiency component.

The determinants of the technical inefficiency in each group can be expressed as follows:

$$(8) \qquad \eta_{ih} = \delta_{0h} + \sum_{j=1}^{4} \delta_{jh} Z_{ijh} + w_{ih} \qquad h = 1, 2, 3$$

where z_{ijh} are the characteristics related to individuals, i.e. the plots in each group following Huang, Huang, and Liu (2014). Five variables are available in our data set: z_{i1h} indicates the location of the plot at a high slope surface, z_{i2h} is its location at a low slope, z_{i3h} represents sandy soil type, z_{i4h} clay soil type, and z_{i5h} lateritic soil type. δ_{0h} and δ_{ih} are the parameters to be estimated, and w_{ih} the error term.

Model Specification in the Second Step

Before specifying the model used for the estimation of the meta-frontier function, it should be shown that the three groups are heterogeneous regarding production technology. The likelihood ratio test is thus used (Huang, Huang, and Liu, 2014). The null hypothesis (H_0) assumes that all production technologies are homogeneous and the pooled method grouping all observations is used for the estimation. The alternative hypothesis (H_1) assumes that these technologies are not homogeneous and that the efficiency of each group should be estimated separately. The likelihood ratio is generated by computing the likelihood values $L(H_0)$ and $L(H_1)$ from the two methods as follows: $\lambda = -2 * \{\ln [L(H_0)] - \ln [L(H_1)]\}$.

The test results give a value of λ= 3, 068.8 which is very high compared to the theoretical value at the 1% threshold. Therefore, the null hypothesis cannot be accepted. The meta-frontier approach is thus more appropriate in analyzing sorghum farmers' technical efficiencies.

The specification of the meta-frontier model in the second step includes all observations and uses the predictions made from equation (7) as follows:

$$(9) \qquad ln\hat{R}_i = \beta_0 + \sum_{j=1}^{4} \beta_j X_{ij} + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4} \beta_{jk} X_{ij} X_{ik} + (\emptyset_{iM} - \eta_{iM})$$

where $ln\hat{R}_i$ records the predicted quantities, β_j and β_{jk} the parameters to be estimated, $\emptyset_{iM}$ the error term, and η_{iM} the term representing the technical inefficiency in the meta-frontier function. X_{ij} are the quantities of inputs used as defined in equation (7).

The determinants of the technical inefficiency in the meta-frontier function can be expressed as follows:

$$(10) \qquad \eta_{iM} = \delta_0 + \sum_{j=1}^{10} \delta_j z_{ij} + w_{iM}$$

where z_{ij} are the variables that explain the technical inefficiency in the second step, δ_j the parameters to be estimated, and w_{iM} . the error term. z_{ij} is composed of the producer's characteristic variables (age, sex, education); the ratio of active members in the producer household; social capital (group membership); income activities; distance to market; extension services; agricultural training; and the collective exploitation of the plot (plot status).

The method consists in estimating equations (7) and (8) simultaneously in the first step and using the predictions to estimate equations (9) and (10) simultaneously in the second step by adopting the stochastic frontier method in both steps.

Data

Data Source

The data used in this study are from a household survey conducted in 2011 in Burkina Faso by the national laboratory *Laboratoire d'Analyse Quantitative Appliquée au Développement-Sahel* (LAQAD-S) as part of the National Land Management Program, Phase 2 (PNGT2). The data collection is based on a sample of 90 communes, three villages per commune, eight households per village. A total of 270 villages and 2,160 households were randomly selected. The objective of conducting the survey was to provide data on the living conditions of rural households across the country and to take appropriate measures to improve their well-being. The data cover different aspects of households, including their demographic characteristics, health, education, livestock, agricultural investments and production, access to land, soil characteristics, access to credit, and access to basic infrastructures.

As many as 1,249 households out of the 2,160 are sorghum growers and the number of plots devoted to sorghum production is 1,643 (the study sample). The data on agricultural production and land tenure are collected at the plot level which is the observation unit in this analysis.

Variables Description

Table 1 presents the mean and standard deviations of the variables used for the empirical analysis. It can be observed at the plot level that households are characterized by a moderate ratio of active members (55.96%), and a low level of formal education (7.9%) which is far below the national rate (around 18%) and reflects the poor education level of rural people (in rural areas, only 2.8% and 1.6% of men and women, respectively, attend primary school, according to a report by the National Institute of Statistic and Demography (INSD, 2012)). Plot owners are predominantly adults (average of 49 years) and male (96.16%), and a low proportion of farmers are trained in agriculture (5.7%) and have consulted extension agents (6.5%). The low proportion of plots owned by women in the sample is explained by the social context of Burkina Faso where households are generally headed by men. Plots are mostly collectively cultivated (family farming) with the household head as the owner (Séogo and Zahonogo, 2019).

Table 1. Description, Mean and Standard Deviation of the Variables Used for the Analysis.

Variables	Description	Mean (Standard Deviation)			
		Formal Rights Group	Customary Rights Group	No Rights Group	Full Sample
Dependent variable					
Output	Quantity of sorghum harvested on the plot (kg)	2, 824.3	936.3	984.5	1, 030.83
		(2, 438.1)	(846.10)	(792.60)	(1, 933.7)
Production variables					
Fertilizer	Quantity of chemical fertilizers applied on the plot (kg)	299.88	10.13	12.41	24.12
		(386.06)	(31.36)	(36.99)	(108.43)
Manure	Number of cartloads of manure used on the plot	19.65	5.315	5.311	5.995
		(30.25)	(7.23)	(6.80)	(10.06)
Labor	Quantity of labor used on the plot (man-days)	159.3	121.33	104.08	121.38
		(153.00)	(91.90)	(73.70)	(94.58)
Area	Area of the plot (ha)	3.96	1.7	1.67	1.811
		(3.76)	(1.30)	(1.19)	(1.57)
Environmental variables in the first step					
High slope	Dummy: 1 if the slope of the plot is high	0.2179	0.1487	0.1976	0.157
Low slope	Dummy: 1 if the slope of the plot is low	0.282	0.3104	0.3952	0.3177
Flat slope	Dummy: 1 if the slope of the plot is flat (reference)	0.5001	0.5409	0.4072	0.5253
Sandy soil	Dummy: 1 if the soil is sandy	0.4358	0.2796	0.2814	0.2872
Clay soil	Dummy: 1 if the soil is clay	0.3076	0.3898	0.3772	0.3846
Lateritic soil	Dummy: 1 if the soil is lateritic	0.1538	0.163	0.2215	0.1685
Stony soil	Dummy: 1 if the soil is stony (reference)	0.1028	0.1676	0.1199	0.1597
Environmental variables in the second step					
Education	Dummy: 1 if the producer has received formal education	0.1538	0.0758	0.0718	0.0791
Age	Age of the producer (years)	50.03	49.5	46.9	49.26
		(14.50)	(14.46)	(11.02)	(14.17)
Gender	Dummy: 1 if the producer is male	0.9487	0.9599	0.982	0.9616
Ratio	Ratio of household active members	0.5285	0.557	0.591	0.5596
		(0.39)	(0.41)	(0.37)	(0.41)
Social capital	Dummy: 1 if the producer is member of a producer group	0.3333	0.0937	0.0898	0.3062
Income activity	Dummy: 1 if the producer is engaged in an income activity	0.282	0.3311	0.3113	0.3749
Distance	Distance to the nearest input market (km)	6.73	8.33	7.58	8.185
		(6.10)	(0.68)	(6.76)	(7.53)
Extension	Dummy: 1 if the producer got a visit of extension agents	0.141	0.0643	0.0419	0.0657
Agri-Training	Dummy: 1 if the producer has received training in agricultu	0.0128	0.0615	0.0479	0.0578
Collective plot	Dummy: 1 if the plot is collectively farmed	0.9743	0.9449	0.9281	0.2288
	Number of observations	78	1, 398	167	1, 643

According to land rights types, a great level of sorghum output and more input use are observed on plots held with formal land rights (see Table 5 for more details on production practices). The owners of these plots received more extension visits (14.10% of the plots in this group and less than 7% in the two other groups) and have more formal education (15.38% and less than 8% in both customary and no-right groups). In the formal land rights group, more than 33% of plots are held by producers who are members to an organization, whereas in the two other groups, this proportion is less than 9.5%. Across the three groups of owners, the farms are generally collectively exploited (more than 90%).

Table 2. Group Specific Stochastic Frontier Parameter Estimates and Plot Level Determinants of Technical Inefficiency.

Variables		Translog Production Function Estimates					
		Formal Land Rights		Customary Land Rights		No Land Rights	
		Coeff	Z-stat	Coeff	Z-stat	Coeff	Z-stat
Constant	C	1.694	0.6	6.8188***	14.96	6.9890***	5.11
Chemical fertilizers	ln X1	0.6298**	2.29	0.4126***	5.59	0.7943***	3.98
Manure	ln X2	0.0362	0.07	0.1748*	1.84	0.3884*	1.65
Labor	ln X3	2.3237*	1.85	-0.2026	-0.97	-0.4129	-0.67
Plot area	ln X4	0.9337	0.99	1.0159***	7.35	0.9939***	2.63
	ln X1 × ln X1	-0.0846***	-2.79	-0.0675***	-8.94	-0.0517***	-2.68
	ln X2 × ln X2	0.2044***	2.82	-0.0859***	-5.16	-0.0376	-1.02
	ln X3 × ln X3	-0.3006*	-1.94	0.0336	1.4	0.0814	1.17
	ln X4 × ln X4	-0.2247	-1.25	0.0170*	0.83	-0.0245	-0.46
	ln X1 × ln X2	-0.0885	-2.78	0.0201**	2.11	-0.0204	-0.76
	ln X1 × ln X3	0.0677	1.16	-0.0037	-0.26	-0.1159***	-2.99
	ln X1 × ln X4	0.0376	0.41	0.0226	1.37	0.2034***	6.07
	ln X2 × ln X3	-0.0248	-0.24	0.0168	0.84	-0.0482	-0.95
	ln X2 × ln X4	0.0421	0.35	-0.0432**	-2	0.0655	1.49
	ln X3 × ln X4	0.0233	0.13	-0.0989***	-3.17	-0.1609*	-1.96
Plot level determinants of technical inefficiency							
Constant		0.4241	0.39	0.0734	0.16	0.5448	1.43
High slope		-1.5934	-1.61	0.072	0.65	-0.136	-0.65
Low slope		-1.8439*	-1.71	-0.6208**	-2.06	-0.6339*	-1.77
Sandy soil		0.4008	0.46	0.0512	0.41	-0.2828	-0.93
Clay soil		0.9219	0.96	-0.04796	-0.39	0.1125	0.48
Lateritic soil		0.3071	0.3	0.0286	0.21	-0.3635	-1.01
	σ^2	1.31		0.5075		0.3512	
	γ	0.95		0.6903		0.8104	
Mean Technical efficiency (%)		70.01		67.47		64.02	
		Chi2 (14)= 164.65***		Chi2 (14)= 1787.26***		Chi2 (14)= 301.89***	
Number of observations		N=78		N=1, 398		N=167	

Results and Discussion

The Stochastic Frontier Estimates and Group Level Determinants of Technical Inefficiency

The estimated parameters and the *z* statistics for the three land rights groups are shown in Table 2. The results suggest that an increase in chemical fertilizers, manure or the plot area is reflected in higher levels of production on plots held under customary rights or without any rights. Chemical fertilizers and labor have a positive and significant effect on production for plots held with formal land rights. These results show the importance of fertilizer use in sorghum production. The positive effect of the land area is reasonable because producers who increase their farm areas also expect an increase in production. In our analysis, formally owned plots are larger and may require a greater use of labor. This may explain why labor significantly affects the level of production in this group.

As for plot level variables, the results show that low plot slope is the main variable that positively and significantly affects the technical efficiency. Because of insufficient rainfall in many agricultural areas, lowlands compared to plains are often the places for potential agricultural production owing to their good water retention. But in the event of excessive rainfall, low slope plots may be associated with poorer performances than flat slope plots.

The Stochastic Meta-frontier Estimates and the Determinants of Technical Inefficiency

This section first discusses the estimated results of the production function before focusing on factors affecting the technical inefficiency of sorghum farmers. The translog production function specification is well suited since the results indicate significant effects of the interactions between inputs on the output.

Like in the first step, the results in Table 3 show that chemical fertilizers, manure, and land area are positively and significantly correlated with production. Chemical fertilizers and organic fertilizers are factors that increase soil endowments favoring plant growth. Soil infertility in Burkina Faso makes the use of fertilizers a necessary condition for better agricultural production. A positive correlation between the plot area and the output level is expected since farmers in Burkina Faso generally tend to increase their production through extensification instead of intensification (Callo-Concha, Gaiser, and Ewert, 2012). These results are similar to the findings of Aduba, Oladunni, and Onojah (2013) in Nigeria indicating that fertilizers and cultivated areas are factors explaining more efficient rice production. Labor does not have a significant effect on production. This result may reflect a situation where the level of labor used is a function of the technology adopted or the type of soil such that different levels of labor used result in the same level of production on a given plot. For example, the use of mechanization by some producers can reduce the amount of labor required for weeding. In addition, for the same area, the quantity of labor used may differ depending on the type of soil.

The results of the environmental variables affecting the technical efficiency are summarized at the bottom of Table 3. It show that the farmer's level of education has a positive effect on his efficiency. Unlike farmers who have no formal education, those with formal education use resources more efficiently. This is consistent with other human capital predictions (Becker, 1993) and similar to the results found by Agboola (2016) for Nigeria.

It is observed that the farmer's age has a non-linear positive effect on production efficiency. In general, farmers gain experience over time and accumulate more resources to better manage their farms (Wozniak, 1987). However, this trend will break at some point as they become inactive in old age, a period during which they lack physical or financial resources.

The results also show that production is more efficient on plots owned by men than those owned by women. This may be due to the fact that women generally do not have time and productive resources such as animal traction, financial resources, and agricultural equipment to better manage their farms. In fact, it is found that men have three times as many resources as women in Burkina Faso (Van den Bold et al., 2013; Agbodji, Batana, and Ouedraogo, 2015) and they are expected to be more efficient. Ng'ombe (2017) found similar results of this gender effect on technical efficiency in Zambia.

Table 3. Stochastic Meta-frontier Parameter Estimates and Determinants of Technical Inefficiency.

Variables		Translog production function estimates	
		Coefficient	Z-Statistic
Constant	C	6.8078	0.22
Chemical fertilizers	$ln\ X1$	0.3607***	5.61
Manure	$ln\ X2$	0.2974***	2.97
Labor	$ln\ X3$	-0.3622	-1.63
Plot area	$ln\ X4$	0.9221***	6.33
	$ln\ X1 \times ln\ X1$	-0.0289***	-4.95
	$ln\ X2 \times ln\ X2$	0.0354**	2.49
	$ln\ X3 \times ln\ X3$	0.0616**	2.4
	$ln\ X4 \times ln\ X4$	-0.0005	-0.03
	$ln\ X1 \times ln\ X2$	0.0135	1.58
	$ln\ X1 \times ln\ X3$	-0.0254**	-1.97
	$ln\ X1 \times ln\ X4$	0.0854***	5.7
	$ln\ X2 \times ln\ X3$	-0.0740***	-3.57
	$ln\ X2 \times ln\ X4$	0.0138	0.62
	$ln\ X3 \times ln\ X4$	-0.0966***	-2.94
The determinants of technical inefficiency in sorghum farming			
Constant		1.3425	0.04
Age		-0.0116*	-1.84
Age squared		0.0001**	2
Sex		-0.1959**	-2.45
Education		-0.1425**	-2.49
Ratio		-0.0354	-0.9
Income activity		0.0549*	1.68
Social capital		-0.1248**	-2.45
Distance to plot		-0.0031	-1.54
Extension services		-0.1192*	-1.91
Agricultural training		0.1031	1.58
Collective plot		-0.1874***	-2.83
	σ^2	0.3599	
	γ	0.0129	
	Mean Technical efficiency	51.96%	
		Chi2 (14)= 1914.36***	
Number of observations = 1,643			

This study uncovered that group membership reduces technical inefficiency in sorghum production. Producers' group memberships enable them to acquire and share ideas and information on appropriate farm management techniques. Social capital is highlighted by Narayan and Pritchett (1999) as one of the ways to mitigate the problems caused by market imperfections in developing countries. Indeed, group memberships afford farmers the privilege of enjoying interacting with one another and assessing information and agricultural credit facilities both from the government and financial institutions (Aduba, Oladunni and Onojah, 2013). This means that producers who are organized in groups are more likely to adopt efficient farm management practices.

Farmers' engagements in non-farm activities are found to have negative effects on technical efficiency. This seems to be an ambiguous result since it is expected that non-farm activities provide farmers with financial resources helping them to efficiently manage their farms. Chiona, Kalinda, and Tembo (2014) found a similar result in Zambia and argued that this could be because farmers who have various sources of income besides crop production are more likely to be preoccupied with other income-generating activities and, hence, pay less attention to important agronomical practices.

Access to extension services is also found to reduce production inefficiency in our analysis. Extension is expected to have a positive effect on production as it enhances farmer access to information and improved technological packages (Aye and Mungatana, 2011). Farmers who consult extension agents are thus better informed about good agricultural practices and can better apply them properly to improve their agricultural performance. Mkhabela (2005) found similar results for extension services in South Africa.

Finally, it is found that farmers are more efficient on plots which are collectively farmed. This result is contrary to the traditional view that economic agents are always in search of their individual interests and are supposed to be more efficient individually than collectively. But in Burkina Faso, farming is generally of a family nature. Production activities are carried out by all household members under the direction of a head in order to satisfy everyone's basic needs. Individual farms are generally implemented by women or younger people in the household to meet their secondary needs. Most of the members' time is spent on the collective farms that sustain the household.

Technical Efficiency and Technology Gap Ratio across Groups

Table 4 shows the results of the technical efficiency and technology gap ratio for the three land tenure regimes. In the meta-frontier approach, it is not appropriate to compare group-specific technical efficiencies. Rather, the MTE and the TGR are comparable. The results show that formal owners are the most efficient. Indeed, the MTE of this group is higher (59.09) than any of the two other groups (51.76 and 52.1 for plots held with customary land rights and plots held with no land rights, respectively). The TGR of formal owners is also the highest, indicating that the frontier in this group is closer to the meta-frontier (i.e. the best technology is used on plots held under formal rights). This evidence may highlight the positive effect of land rights security on the adoption of technologies to stimulate agricultural production. Indeed, the acquisition of formal land rights allows farmers to protect their land against any encroachment, giving them an incentive to adopt the best farm management practices as they are sure of reaping all benefits from their efforts.

These results are comparable to the work of Donkor and Owusu (2014) in Nigeria, which showed that land tenure is an essential factor that can influence producers' performances. They highlighted a positive relationship between land ownership and technical efficiency in rice production. Shittu et al. (2018) also suggested the promotion of private land ownership in Nigeria to strengthen rural land governance towards sustainable land use and agricultural production. Feng

(2008) showed in China that there is a difference in efficiency between different rice producers depending on how the land is acquired. The study of Zhang et al. (2011) supports that by revealing a positive impact of land reallocation on technical efficiency in China. The findings of Ogundaria and Awokuse (2016) in Thailand also indicated that securing land rights through formalization encourages producers to put more efforts into production, thus increasing their efficiency.

Table 4. Technical Efficiency and Technology Gap Ratio across Groups.

Land Rights Groups	Technical Efficiency (TE)	Technology Gap Ratio (TGR)	Meta Technical Efficiency (MTE)
Plots held with Formal Land Rights	70.01	0.8439	59.09
Plots held with Customary Land Rights	67.47	0.7671	51.76
Plots held with No Land Rights	64.02	0.8138	52.1

The adoption of the meta-frontier approach is found to be appropriate in this analysis. Indeed, the statistics on the use of production factors in Table 5 show differences in the combination of production techniques between the three groups. Formal owners cultivate larger plots of about 4 ha, on average, compared to about 1.70 ha and 1.67 ha for customary owners and non-owners, respectively. In terms of equipment, more than 80% of the plots held by formal rights belong to producers with animal traction, while it is less than 75% and 65% for the non-owners and the customary owners, respectively. Fertilizers are more often used on formally owned plots, whereas adoption rates of water and soil conservation techniques are higher on customary-owned ones. The difference test shows that the gaps in input use are statistically significant across groups. A substantial result is that fertilizer use intensity in the formal rights group is nearly five times higher than the other two groups. There is evidence of technology heterogeneity across groups justifying the adoption of the meta-frontier method.

Table 5. Differences in Input Use Between the Land Rights Groups.

Variables	Plots held with Formal Land Rights	Plots held with Customary Land Rights	Plots held with No Rights
Mean plot area (ha)	3.968	1.707	1.677
Land holder possession of equipment for traction (%)	83.33	61.73	73.05
Use of water and soil management technologies (%)	1.28	27.89	13.17
Fertilizers use intensity (kg/ha)	105.4	19.44	25.56
Manure use intensity (cartload/ha)	6.57	3.7	4.43

Conclusions

This study analyzes the technical efficiency of sorghum production. It compares TGR and MTE between three land rights groups and identifies factors explaining production efficiency. The stochastic meta-frontier approach is used by specifying a translog frontier production function. The estimation of the frontier function by the maximum likelihood method provided consistent results.

The results show that chemical fertilizers, manure, and the plot area devoted to sorghum farming are the main inputs that explain the level of production reached by farmers. Moreover, these results highlight the existence of a technical inefficiency in sorghum production. It is also observed that production is more efficient on plots held with formal property rights. Such rights could provide more land tenure security and incite farmers to efficiently manage the resources used in crop production.

The results provide evidence that there is a significant gain in terms of technical efficiency to be obtained by households engaged in sorghum farming. Indeed, the technical efficiency is estimated at 69% and this suggests a possibility for farmers to increase the levels of their harvested output by 31% without resorting to an increase in agricultural investment or farm areas. Thus, it is important to implement policies that aim at reducing production inefficiency. The progressive and non-conflicting formalization of land property rights is one of the mechanisms to be promoted in order to stimulate technical efficiency and improve agricultural performance. Since competition for land is increasingly inducing tenure insecurity, farmers in the customary system must be encouraged to formalize their land rights by acquiring at least the APFR which protects their land from any encroachments. Formalization may also have a positive effect on access to land for vulnerable groups (such as women and migrants) and develop the land market.

Formalization must take into account the social context of Burkina Faso characterized by the collective status of farming. The transfer of land from the farmer to his descendants must be guaranteed without risk of conflict. It must aim at securing not only individual rights, but also collective rights. A successful land tenure transformation will probably contribute to agricultural development and poverty alleviation in rural areas.

The results also reveal that social capital, formal education, and extension services reduce technical inefficiency. This implies that the training of farmers, the development of extension service institutions at local levels, and the development of farmer-based organizations could be policy instruments for improving production efficiency. Decision makers should consider those factors in agricultural policies to increase household food security.

Although the stochastic meta-frontier approach has yielded robust results, there are limitations to the use of cross-sectional data. Some unobservable factors can influence production and, in such a situation, the use of cross-sectional data can lead to biased estimates. The use of panel data makes it possible to correct this bias and takes into account the dynamic behavior of farmers (Coelli, 1995; McDonald and Roberts, 1999). Future studies with panel data could enrich the topic addressed in this analysis.

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