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Land tenure context shapes the gender gap in the technical efficiency of smallholder plots in Burkina Faso

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Abstract

We study how the gender of the plot manager and tenure security jointly shape technical efficiency in smallholder agriculture, using 318,960 plot-season observations from eight rounds of Burkina Faso's Permanent Agricultural Survey (2014-2024). We estimate a one-step translog stochastic frontier in which the variance of the half-normal inefficiency term depends on gender, tenure status and their interaction, with village-clustered sandwich standard errors obtained by automatic differentiation. Efficiency scores from a homoscedastic frontier are then analysed in a four-level within-between hybrid model (plot, household-season, household, village) with random slopes and cross-level interactions, and a frontier-based decomposition splits the gender productivity gap into endowment, crop and inefficiency components. Mean technical efficiency is 0.57. Gender and tenure have no significant effect on the inefficiency variance once headship and length of tenure are controlled for. Within households, women's plots are about 1.5% less efficient, and the gap widens with the village share of borrowed land and vanishes in female-headed households. Inefficiency accounts for 27% of the raw gender gap in output value per hectare, endowments for about half. The attempt to add village fixed effects to the frontier shows that much of the pooled inefficiency is village-level heterogeneity, a caveat for frontier studies on survey data.

Keywords: stochastic frontier; heteroscedastic inefficiency; multilevel model; gender gap; land tenure; Burkina Faso

JEL classification: D24; Q12; Q15; J16; C23

1. Introduction

The agricultural productivity gap between men and women is one of the best-established stylised facts in the development economics of sub-Saharan Africa. Studies based on LSMS-ISA surveys document substantial productivity gaps at the expense of women-managed plots, often above 20%, and show that most of the gap stems from differences in endowments: labour, inputs, land and crops (Peterman et al., 2011; Kilic et al., 2015; Doss, 2018). In Burkina Faso, Udry et al. (1995) and Udry (1996) showed that households allocate inputs inefficiently across men's and women's plots, and Kazianga and Wahhaj (2013) attribute the advantage of the household head's plots to social norms governing the organisation of labour.

Two angles nonetheless remain under-explored. The first is technical efficiency, the ability to obtain maximum output from a given combination of inputs. Most studies decompose the yield gap into endowment and "returns" effects (Oaxaca, 1973; Blinder, 1973) without separating the

position of the production frontier from the distance to it. This distinction matters for policy: an endowment deficit calls for input transfers, whereas an efficiency deficit calls for interventions on management, information or institutional constraints. The second angle is land tenure as a mediator of the gender gap. Women mostly access land through derived rights (loans, allocation by the household head) that are more revocable than men's. Yet tenure studies focus on investment (Besley, 1995; Goldstein & Udry, 2008; Bambio & Bouayad Agha, 2018), rarely on efficiency, and almost never cross gender and tenure at several levels.

This paper fills these gaps using eight rounds of Burkina Faso's Permanent Agricultural Survey (EPA), 318,960 plot-seasons observed between 2014 and 2024. Our approach has three steps. **(i)** We estimate a one-step translog stochastic frontier (Battese & Coelli, 1995) in which the variance of inefficiency depends on manager gender, tenure status and their interaction, avoiding the bias of two-step procedures (Wang & Schmidt, 2002). **(ii)** We analyse efficiency scores in a four-level within-between hybrid model, with plot, household-season, household and village levels (Mundlak, 1978; Bell & Jones, 2015). The model separates the within-household gender gap, the household composition effect and the village contextual effect, and lets the gender gap vary across villages. **(iii)** We decompose the gender productivity gap into contributions from endowments, plot quality, crop choice and technical inefficiency, overall and within households.

The results qualify the notion of "female inefficiency". The raw productivity gap of 13.2 log points halves within households. Technical inefficiency explains a quarter to a third of it, lower input endowments about half of the raw gap. Within households, women's plots are about 1.5% less efficient, a small but robust gap. Contrary to intuition, precarious tenure has no direct effect on technical efficiency. It operates through context: the gender gap widens in villages where land borrowing is widespread, vanishes in female-headed households and narrows in villages where women manage a large share of plots. The efficiency gap thus appears to be a consequence of women's social position in land and labour systems rather than of lower farming skills.

Section 2 presents the context, Section 3 the conceptual framework, Section 4 the data and Section 5 the methodology. Section 6 reports the results, Section 7 discusses them and Section 8 concludes.

2. Context: gender, land rights and the organisation of production

In most farming systems of Burkina Faso, the family farm is organised around collective fields managed by the household head, alongside individual plots assigned to wives, junior men and sometimes children. Women cultivate these personal plots while also working on the collective fields, whose output is destined for common consumption (Kazianga & Wahhaj, 2013). Women's access to land almost always runs through derived rights: the plot is allocated by the husband or the lineage, or borrowed from a third party, and it can be reclaimed, reduced or moved from one season to the next. Law No. 034-2009/AN on rural land tenure recognises equal access to land for men and women and provides for measures in favour of vulnerable groups, but its implementation remains limited.

Our data confirm this asymmetry. Women manage 35% of rainfed field-crop plots. About 69% of their plots are held under precarious tenure (80% of them borrowed), against 24% of men's plots. Their plots are smaller (0.26 ha versus 0.64 ha), more often planted with legumes and groundnut than with cereals, and receive about half as much mineral fertilizer and a third as much manure. In 67% of household-seasons, men's and women's plots coexist, enabling within-household comparisons. Female-headed households (5% of plots) are a special case: the woman is both manager and head, and has more direct control over land and labour.

3. Conceptual framework and hypotheses

We distinguish two channels through which gender and tenure may affect land productivity (Fig. 1). The endowment channel shifts the production frontier: input quantities, plot quality and location, crop choice. The management channel determines the distance to the frontier: for given inputs, a plot produces below its potential because operations are late, collective labour is mobilised first on the head's fields, or technical information is lacking. Precarious tenure may affect efficiency through three mechanisms: a short horizon that discourages fertility management practices, uncertainty about which plot will be allocated from one season to the next, which limits learning about its characteristics, and lower priority in the allocation of household labour and equipment.

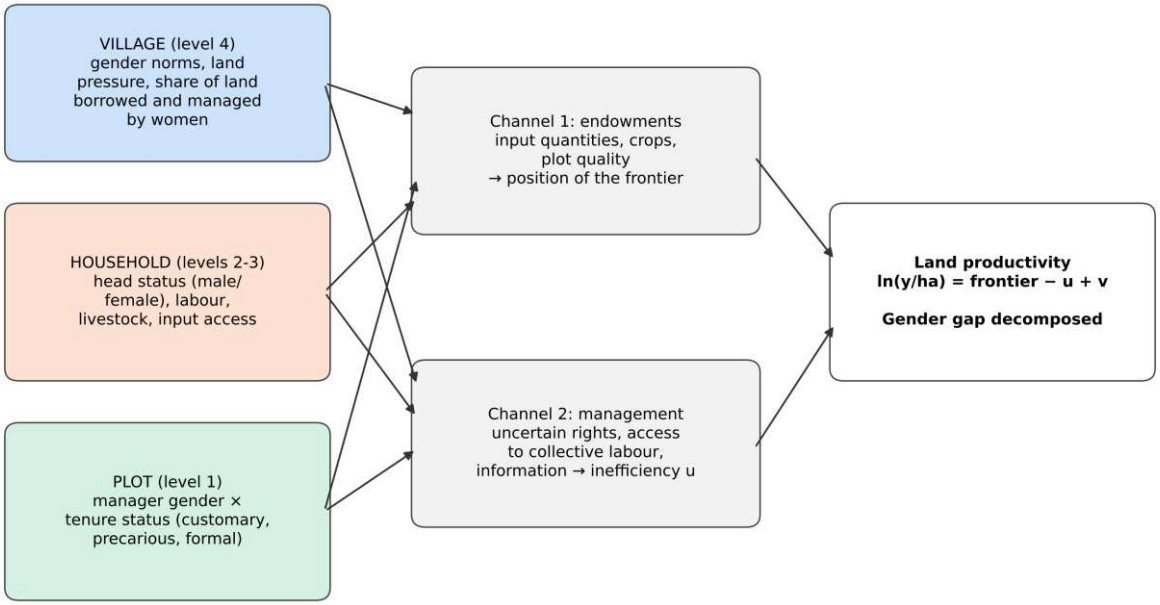

Fig. 1 Conceptual framework: gender, tenure and technical efficiency at several levels. *Source:* author.

These mechanisms are nested within higher-level structures. At the household level, the head's gender determines who controls family labour and inputs. At the village level, gender norms, land pressure and the prevalence of land lending shape the effective security of derived rights. We test four hypotheses. **H1**: for given inputs, women-managed plots are less technically efficient than men's plots in the same household. **H2**: precarious tenure reduces technical efficiency, more so for women (a "double penalty"). **H3**: the gender gap is attenuated in female-headed households. **H4**: the gender gap varies across villages; it is wider where land borrowing is widespread and narrower where female plot management is an established norm.

4. Data and variables

We use the Permanent Agricultural Survey (EPA) conducted by the statistics directorate (DGESS) of the Ministry of Agriculture, an annual national two-stage survey (villages, then farm households) stratified by agricultural potential and farm size. We use two harmonised panels, panel A (2014/15 to 2019/20) and panel B (2023/24 and 2024/25), and merge the plot, household and product-use files. The sample retains rainfed field-crop plots (cereals, cotton, oilseeds and legumes, roots and tubers) of at least 0.01 ha with positive output. It comprises 318,960 plot-seasons, 34.8% of them managed by women, from 11,222 households and 1,780 villages.

Output is the value of main-crop production at 2023–2024 national median prices (for instance 196 FCFA/kg for maize and 250 FCFA/kg for groundnut), which allows crops to be aggregated

in a single frontier; yields are winsorised by crop and season. Frontier inputs are area, mineral fertilizer (NPK and urea), seed, manure, SWC structures, improved seed, traction, hired and mutual-aid labour, herbicide and the household labour-to-land ratio. Physical plot characteristics (lowland, slope, location, reclaimed land, years since fallow, intercropping), crop fixed effects and region-by-season fixed effects complete the specification. Gender is the sex of the plot manager. Tenure distinguishes precarious tenure (loan, rental or transfer without possession rights), formal documents and customary possession (reference). Table 1 reports descriptive statistics.

Table 1. Descriptive statistics by manager gender and tenure status (means), EPA 2014–2024

Variable	Men, secure	Men, precarious	Women, secure	Women, precarious	All	M/F gap signif. (1%)
Output and area						
Output value (thousand FCFA/ha)	257.5	266.8	223.2	217.6	245.7	yes
Area (ha)	0.64	0.63	0.28	0.24	0.50	yes
Inputs						
NPK + urea (kg/ha)	55.6	57.7	26.9	21.0	44.5	yes
Seed (kg/ha)	38.2	36.8	63.8	64.2	47.0	yes
Manure (0/1)	0.296	0.197	0.120	0.070	0.208	yes
SWC (0/1)	0.149	0.093	0.125	0.102	0.127	yes
Improved seed (0/1)	0.145	0.154	0.069	0.043	0.114	yes
Animal/motor traction (0/1)	0.723	0.794	0.614	0.677	0.711	yes
Hired labour (0/1)	0.117	0.127	0.077	0.063	0.101	yes
Mutual-aid labour (0/1)	0.337	0.324	0.278	0.247	0.307	yes
Herbicide (0/1)	0.410	0.578	0.339	0.341	0.412	yes
Plot and crops						
Lowland (0/1)	0.057	0.062	0.100	0.096	0.072	yes
Outfield (0/1)	0.475	0.563	0.542	0.629	0.533	yes
Length of tenure (years)	19.3	12.3	13.9	7.8	14.9	yes
Cereals (0/1)	0.728	0.603	0.451	0.365	0.592	yes
Oilseeds/legumes (0/1)	0.199	0.321	0.537	0.625	0.356	yes
Manager and household						
Age (years)	48.4	43.3	40.4	39.4	44.6	yes
Schooled (0/1)	0.205	0.253	0.117	0.119	0.182	yes
Household head (0/1)	0.882	0.726	0.175	0.071	0.587	yes
Female-headed household (0/1)	0.008	0.013	0.214	0.099	0.053	yes
Efficiency						
Technical efficiency (homoscedastic frontier)	0.578	0.577	0.567	0.563	0.573	yes
Plot-seasons	158,892	49,053	34,567	76,448	318,960	

Note: "secure" combines customary possession and formal documents. Last column: Welch test of equal means between men's and women's plots at the 1% level. *Source:* author's calculations from the EPA (DGESS).

The contrasts are sharp (Table 1). Women's plots produce 13–18% less value per hectare than men's plots depending on tenure status, even though they are smaller, which under the inverse farm size–productivity relationship should favour them. They receive less than half as much

mineral fertilizer per hectare and much less manure, improved seed and outside labour, but more seed per hectare, reflecting the weight of legumes. Mean technical efficiency, from the frontier described below, varies little across the four groups (0.563 to 0.578; Fig. 2): most of the productivity differences thus stem from endowments, which the decomposition in Section 6.5 quantifies.

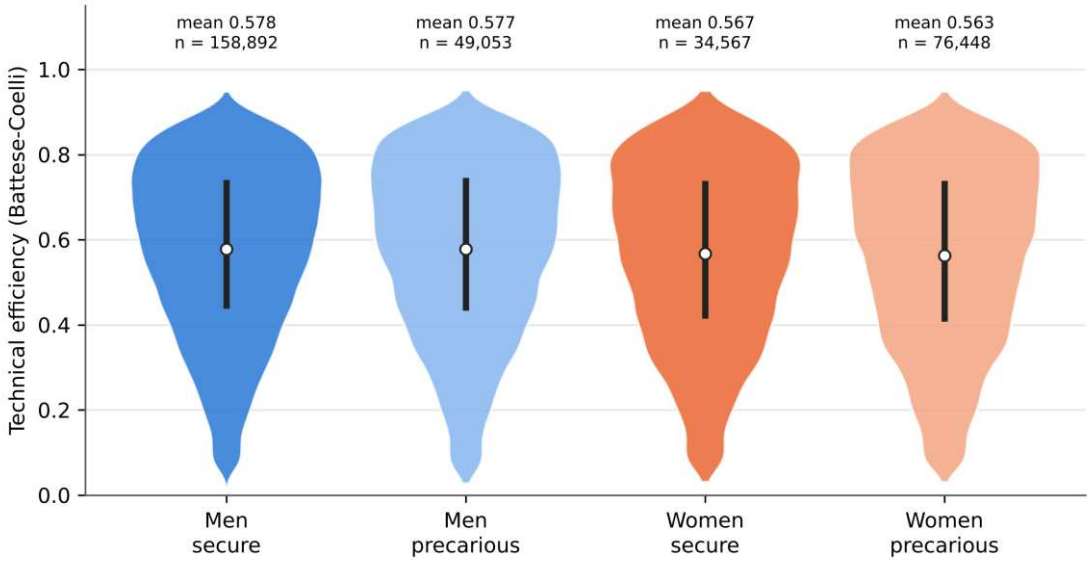

Fig. 2 Distribution of technical efficiency by manager gender and tenure status (densities, interquartile range and mean). *Source:* author's calculations.

5. Methodology

5.1. One-step stochastic frontier

For plot *i*, we specify a translog frontier in area (A), fertilizer (F) and seed (S), augmented with qualitative inputs and plot characteristics (Aigner et al., 1977; Meeusen & van den Broeck, 1977):

$$lny_i = \alpha_c + \alpha_{rt} + \sum_k \beta_k \, lnx_{ki} + \frac{1}{2}\sum_k \sum_l \beta_{kl} \, lnx_{ki} lnx_{li} + W_i'\gamma + v_i - u_i \quad (1)$$

where y is output value, $x = (A, 1+F, 1+S)$ are inputs in centred logarithms, W collects qualitative inputs and plot characteristics, α_c are crop fixed effects and α_{rt} region-by-season fixed effects. The noise term $v_i \sim N(0, \sigma_v^2)$ captures shocks and measurement error. Inefficiency $u_i \geq 0$ follows a heteroscedastic half-normal distribution (Caudill et al., 1995) :

$$u_i \sim N^+(0, \sigma_{ui}^2), ln\sigma_{ui}^2 = \delta_0 + \delta_1 Female_i + \delta_2 Precarious_i + \delta_3 Formal_i + \delta_4 Female_i \times Precarious_i + \delta_5 Female_i \times Formal_i + Z_i'\eta \quad (2)$$

Z includes the manager's age, schooling and headship, length of tenure, the head's gender and literacy, household size, livestock, producer organisation membership, the village share of

precarious land and a panel B dummy. A positive δ means more inefficiency. The frontier and the inefficiency equation are estimated jointly by maximum likelihood, avoiding the bias of two-step approaches (Wang & Schmidt, 2002). Estimation is implemented in Python with automatic differentiation (JAX), with sandwich standard errors clustered by village. Plot efficiency is predicted as $TE_i = E[e^{-u_i}|\varepsilon_i]$ (Battese & Coelli, 1988) and the inefficiency component as $E[u_i|\varepsilon_i]$ (Jondrow et al., 1982).

With $\varepsilon_i = v_i - u_i$, $\sigma_i^2 = \sigma_{ui}^2 + \sigma_V^2$ and $\lambda_i = \sigma_{ui}/\sigma_V$ the log-likelihood is (Aigner et al., 1977; Caudill et al., 1995) :

$$lnL = \sum_i [ln2 - ln\sigma_i + ln\varphi(\varepsilon_i/\sigma_i) + ln\Phi(-\varepsilon_i\lambda_i/\sigma_i)] \quad (2b)$$

Crop and region-by-season intercepts enter the frontier as fixed effects (one normalised to zero), giving about 160 parameters. The likelihood is maximised with L-BFGS using exact gradients from automatic differentiation; the Hessian is accumulated over data chunks, and village-clustered sandwich standard errors combine it with cluster sums of observation-level scores. Because $E[u_i] = \sigma_{ui}(2/\pi)^{1/2}$, the marginal effect of a determinant z_j on expected inefficiency is $\partial E[u_i]/\partial z_i = (\delta_i/2)E[u_i]$, which we report at the sample mean (Kumbhakar & Lovell, 2000; Wang & Schmidt, 2002). Heteroscedasticity in *u* matters for consistency of the frontier itself: ignoring it biases both the intercept and the slope coefficients (Caudill et al., 1995).

5.2. Multilevel analysis of efficiency

The one-step frontier treats plots as independent and does not distinguish levels. To analyse the structure of efficiency, we predict TE from a homoscedastic frontier with no inefficiency covariates, so that the scores do not mechanically embed the determinants we wish to test. We then estimate a hybrid model with four nested levels, plot, household-season, household and village, plus a crossed village-by-season level (Mundlak, 1978; Bell & Jones, 2015):

$$lnTE_{ihVt} = \beta_w'(G_{ihVt} - \bar{G}_{hVt}) + \beta_B'\bar{G}_{hVt} + \beta_V'C_{V(-h)t} + X'\theta + \lambda_c + \tau_t + u_V + u_{Vt} + u_h + u_{ht} + e_{ihVt} \quad (3)$$

where G stacks the female, precarious and formal indicators and the female × precarious interaction. The split into deviations from the household-season mean (within effect, β_w) and the mean itself (composition effect, β_B) reproduces the household-by-season fixed-effects estimator while retaining the higher levels. C contains the village shares (excluding the household) of precarious land, documented land and women-managed plots. **M1** has random intercepts at all levels. **M2** adds village random slopes for the within-household gender and

tenure effects. **M3** adds cross-level interactions of the within-household female indicator with the village shares and with female headship. Models are estimated by maximum likelihood with lme4 (Bates et al., 2015), with Satterthwaite degrees of freedom (Kuznetsova et al., 2017). As a complement, we estimate household-by-season and manager-by-season fixed-effects regressions with village-clustered standard errors.

5.3. Decomposing the gender gap

The frontier yields an exact decomposition of the mean land productivity gap between men's (*M*) and women's (*F*) plots:

$$\Delta ln(y/A) = \sum_k \hat{\beta}_k \Delta \bar{x}_k + \Delta \bar{\alpha} + [-\Delta E(u|\varepsilon)] + \Delta \bar{v} \qquad (4)$$

The terms are, respectively, the contribution of inputs and plot quality (evaluated at the common frontier coefficients), of crops and region-by-season effects, of technical inefficiency and of noise. We apply it to the raw gap and to the within-household gap (variables centred on household-season means, mixed-gender households only), and separately for secure and precarious plots. Unlike a standard Oaxaca–Blinder decomposition, it isolates the distance to the frontier instead of conflating it with an unexplained "returns" effect.

6. Results

6.1. The production frontier and the determinants of inefficiency

Table 2 reports the one-step frontier. Output elasticities at the sample mean are 1.01 for area, 0.033 for seed and 0.003 for fertilizer, although the positive quadratic term implies that the fertilizer elasticity rises with the dose. Among qualitative inputs, herbicide (+0.072), improved seed (+0.056), hired (+0.031) and mutual-aid labour (+0.027) and manure (+0.023) shift the frontier upwards significantly. The standard deviation of inefficiency is about 3.5 times that of noise, and mean technical efficiency is 0.574 (median 0.601). The average distance to the frontier is therefore large, although, as always with survey data, it also reflects unobserved heterogeneity and measurement error. The likelihood-ratio test strongly rejects homoscedastic inefficiency ($\chi^2 = 1{,}944; 17\ df$).

In the inefficiency equation, neither gender nor tenure has a significant effect once headship, length of tenure and household characteristics are controlled for. The female coefficient is positive but imprecise (+0.041, SE 0.029), the precarious coefficient is close to zero (+0.011), as is their interaction (+0.002). The significant determinants are of a different nature. Being the household head reduces inefficiency (−0.124), in line with Kazianga and Wahhaj's (2013) argument about the priority given to the head's fields. So do the length of tenure of the plot

(−0.024 per decade), livestock, the head's literacy and producer organisation membership. Panel B (2023–2024) is more efficient than panel A (Fig. 3). Evaluated at the sample mean of E[u] (0.683), the marginal effects imply that a female manager raises expected inefficiency by only 0.014 and precarious tenure by 0.004, against −0.042 for headship and −0.054 for panel B. This matters: in comparisons across the whole sample, gender and tenure status do not affect efficiency independently of the manager's social status and the age of the right. Yet these two dimensions are precisely what distinguish women and borrowers: only 18% of women's secure plots and 7% of their precarious plots are managed by a female household head.

Table 2. Translog stochastic production frontier and determinants of inefficiency (one-step estimation)

	(1) All crops	**(2) Cereals**	**(3) Homoscedastic**
Frontier (elasticities at the mean)			
ln area	1.014***	1.022***	1.017***
	(0.003)	(0.003)	(0.003)
ln(1 + fertilizer)	0.003	0.007*	0.004
	(0.004)	(0.004)	(0.004)
ln(1 + seed)	0.033***	0.032***	0.033***
	(0.004)	(0.005)	(0.004)
½ ln area²	−0.003	−0.010***	−0.002
	(0.003)	(0.003)	(0.003)
½ ln(1 + fertilizer)²	0.029***	0.025***	0.030***
	(0.003)	(0.004)	(0.003)
½ ln(1 + seed)²	−0.011***	−0.014***	−0.010***
	(0.003)	(0.004)	(0.003)
Manure	0.023***	0.029***	0.028***
	(0.007)	(0.007)	(0.007)
Improved seed	0.056***	0.053***	0.057***
	(0.011)	(0.012)	(0.011)
Hired labour	0.031***	0.033***	0.031***
	(0.010)	(0.011)	(0.010)
Mutual-aid labour	0.027***	0.016*	0.027***
	(0.007)	(0.008)	(0.007)
Herbicide	0.072***	0.077***	0.073***
	(0.008)	(0.009)	(0.008)
Intercropped	−0.090***	−0.102***	−0.093***
	(0.007)	(0.008)	(0.007)
Inefficiency equation: ln σ^2_u			
Female manager	0.041	0.068*	
	(0.029)	(0.037)	
Precarious tenure	0.011	−0.049*	
	(0.021)	(0.026)	
Formal document	−0.120	−0.127	
	(0.096)	(0.108)	

	(1) All crops	(2) Cereals	(3) Homoscedastic
Female × precarious	0.002	0.034	
	(0.037)	(0.046)	
Female × formal	0.165	0.121	
	(0.108)	(0.131)	
Manager is household head	−0.124***	−0.109***	
	(0.022)	(0.028)	
Length of tenure (10 years)	−0.024***	−0.007	
	(0.008)	(0.009)	
Female-headed household	−0.035	−0.042	
	(0.039)	(0.046)	
ln(1 + TLU)	−0.063***	−0.063***	
	(0.013)	(0.015)	
Producer organisation	−0.046*	−0.062**	
	(0.024)	(0.028)	
Village precarious share	0.052	−0.008	
	(0.051)	(0.057)	
Panel B (2023–2024)	−0.158***	−0.142***	
	(0.038)	(0.046)	
ln σ_v	−1.402***	−1.327***	−1.402***
	(0.013)	(0.015)	(0.014)
Mean technical efficiency	0.574	0.596	0.573
Log-likelihood	−256,802	−144,545	−257,774
Observations	318,960	188,782	318,960

Note: dependent variable: ln(value of main-crop output). Inputs in centred logarithms. All columns include crop and region × season fixed effects. The frontier also controls for SWC, traction, labour-to-land ratio, lowland, slope, location, reclaimed land and years since fallow; the inefficiency equation also controls for manager age and schooling, head literacy, household size and a missing-tenure-length dummy. Sandwich standard errors clustered by village in parentheses. *** p < 0.01; ** p < 0.05; * p < 0.1.

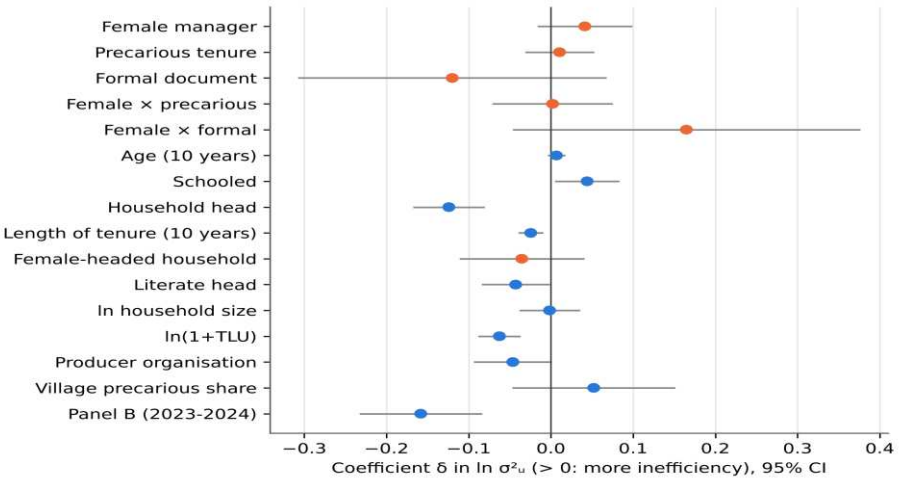

Fig. 3 Determinants of technical inefficiency: δ coefficients of the variance equation (model 1, 95% CI). Gender and tenure variables in orange. *Source:* author's calculations.

6.2. Multilevel variance decomposition of efficiency

Fig. 4 decomposes the variance of ln(TE) and ln(value/ha). For efficiency, 65% of the variance lies between plots of the same household-season, 30% between villages (including 17% from village-by-season shocks) and only 6% between households of the same village. Inefficiency is thus first a plot-level phenomenon, which justifies comparing men's and women's plots within households, and secondly a village-level phenomenon. Differences in household "ability" weigh little.

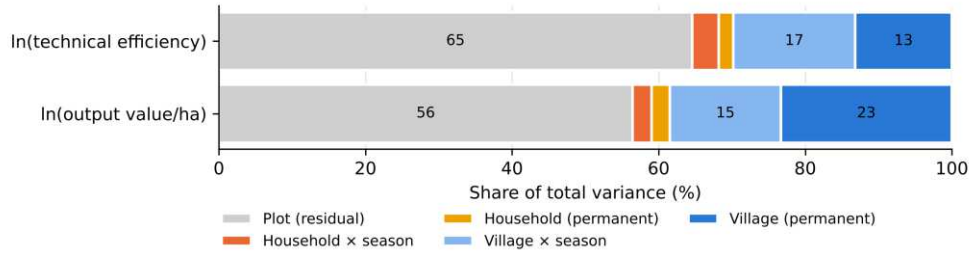

Fig. 4 Variance decomposition by level (null models with four nested levels and a crossed village × season level). *Source:* author's calculations.

6.3. Gender and tenure gaps within households

Table 3 reports within-household comparisons. Within a household and season, a woman-managed plot is 1.4% less efficient ($p = 0.010$) and 3.6% less productive. H1 is confirmed, but the efficiency gap is modest. Precarious tenure has no average effect on efficiency (+0.002), including when comparing plots of the same manager (−0.013, $p = 0.104$). Separate regressions by gender, however, reveal an asymmetry. For women, a precarious plot is 2.5% less efficient than a secure plot managed by a woman of the same household ($p = 0.003$) and 3.4% less productive. For men, the effect is weaker (−0.011, $p = 0.074$). The female × precarious interaction is significant for productivity (−0.021, $p = 0.019$) but not for efficiency (−0.010). The double penalty (H2) thus exists mainly in productivity, and only partly in efficiency.

The head's gender is decisive. In male-headed households, the gender efficiency gap reaches 2.3% ($p < 0.001$) and the productivity gap 5.0%. In female-headed households there is no gender gap, either in efficiency (+0.012, $p = 0.458$) or in productivity (−0.008). H3 is confirmed: the gender gap is not a property of women as farmers but of their position as dependants in male-headed households. In female-headed households, precarious tenure weighs heavily (−0.044 on efficiency), suggesting that these households depend on more fragile land loans.

Table 3. Within-household efficiency and productivity gaps by gender and tenure (fixed-effects OLS)

	All	Same manager	Women's plots	Men's plots	Male-headed HH	Female-headed HH
ln(technical efficiency)						
Female manager	−0.014***				−0.023***	0.012
	(0.006)				(0.005)	(0.016)
Precarious tenure	0.002	−0.013	−0.025***	−0.011*	−0.001	−0.044***
	(0.006)	(0.008)	(0.008)	(0.006)	(0.005)	(0.015)
Formal document	−0.017	−0.020	−0.042*	−0.012	−0.011	−0.133***
	(0.012)	(0.018)	(0.024)	(0.015)	(0.012)	(0.048)
Female × precarious	−0.010					
	(0.007)					
Manager is head	0.009*		0.011	0.004	0.004	0.023
	(0.004)		(0.011)	(0.007)	(0.005)	(0.015)
ln(output value/ha)						
Female manager	−0.036***				−0.050***	−0.008
	(0.007)				(0.006)	(0.020)
Precarious tenure	0.011	−0.011	−0.034***	−0.010	0.005	−0.057***
	(0.007)	(0.010)	(0.010)	(0.008)	(0.006)	(0.018)
Formal document	−0.017	−0.009	−0.063**	−0.004	−0.007	−0.182***
	(0.015)	(0.024)	(0.031)	(0.019)	(0.015)	(0.068)
Female × precarious	−0.021**					
	(0.009)					
Manager is head	0.032***		0.028**	0.024***	0.027***	0.043**
	(0.006)		(0.014)	(0.009)	(0.006)	(0.018)
Observations	317,708	274,451	105,743	205,661	301,009	16,699
Fixed effects	HH×season	Mgr×season	HH×season	HH×season	HH×season	HH×season

Note: all specifications include crop fixed effects and control for manager age and schooling, length of tenure and plot location. ln(TE) comes from the homoscedastic frontier. Standard errors clustered by village in parentheses. *** p < 0.01; ** p < 0.05; * p < 0.1.

6.4. Multilevel hybrid model: the role of context

Table 4 reports the hybrid models. In M1, the within-household gender effect on efficiency (−0.013) is close to the fixed-effects estimate, and the female × precarious interaction is negative and significant (−0.010, p = 0.021), which provides additional support for the double penalty. The composition effect of gender is more than twice the within-household effect (−0.032): households in which a large share of plots is managed by women are less efficient overall, including on men's plots. The contextual effect of the village share of women-managed plots is also negative (−0.036). For productivity, the same effects are about twice as large: −0.035 for gender, −0.021 for the female × precarious interaction and −0.069 for the composition effect.

The village random slope for gender (M2) improves fit markedly ($\chi^2 = 2{,}871$). The village-level standard deviation of the gender effect on efficiency (0.109) is almost seven times the mean effect: the gender gap is negative in 59% of villages but zero or positive elsewhere (Fig. 5). The cross-level interactions (M3) shed light on this heterogeneity, as predicted by H4. **(i)** The gender gap widens with the village share of precarious land: −0.021 (p = 0.039) for efficiency and −0.035 (p = 0.007) for productivity. Where borrowing is the norm, women, who are the main borrowers, bear more of its consequences. **(ii)** It narrows sharply with the village share of women-managed plots (+0.066, p < 0.001): where female plot management is established, women's access to labour, equipment and information appears less constrained. **(iii)** It almost disappears in female-headed households (+0.026, p = 0.057). The village share of documented land does not alter the gap (−0.001).

Table 4. Multilevel hybrid models of technical efficiency and productivity

	ln(technical efficiency)	**ln(output value/ha)**
M1 — Random intercepts		
Female, within household	−0.013***	−0.035***
	(0.004)	(0.005)
Precarious, within household	0.002	0.014***
	(0.003)	(0.004)
Formal, within household	−0.017*	−0.017
	(0.010)	(0.012)
Female × precarious, within	−0.010**	−0.021***
	(0.004)	(0.005)
Household share of female plots	−0.032***	−0.069***
	(0.009)	(0.012)
Household share of precarious plots	−0.007	0.003
	(0.006)	(0.007)
Village share of female plots	−0.036**	−0.095***
	(0.017)	(0.023)
Village precarious share	0.013	0.041***
	(0.010)	(0.014)
Village formal share	0.019	0.026
	(0.028)	(0.036)
Female-headed household	0.024***	0.042***
	(0.007)	(0.008)
Manager is household head	0.010***	0.032***
	(0.003)	(0.004)
M2 — Village random slopes		
Female, within household	−0.016***	−0.042***
	(0.005)	(0.006)
SD of "female" slope	0.109	0.144
SD of "precarious" slope	0.090	0.118

	ln(technical efficiency)	ln(output value/ha)
LR $\chi^2(2)$, M2 vs M1	2,871***	3,471***
M3 — Cross-level interactions		
Female, within household	−0.023***	−0.051***
	(0.005)	(0.007)
× village precarious share	−0.021**	−0.035***
	(0.010)	(0.013)
× village formal share	−0.001	−0.023
	(0.025)	(0.030)
× village female share	0.066***	0.123***
	(0.016)	(0.020)
× female-headed household	0.026*	0.025
	(0.014)	(0.017)
Precarious × village precarious share	0.006	0.004
	(0.014)	(0.017)
Observations	318,960	318,960

Note: maximum likelihood (lme4). All models include manager controls (age, schooling, headship, length of tenure) and household controls (area, labour-to-land ratio, TLU, size, head literacy and age, producer organisation, metal roof), crop and season fixed effects, and random intercepts for village, village × season, household and household × season. Within variables are centred on household-season means; village shares exclude the household and are centred. Satterthwaite standard errors in parentheses. *** p < 0.01; ** p < 0.05; * p < 0.1.

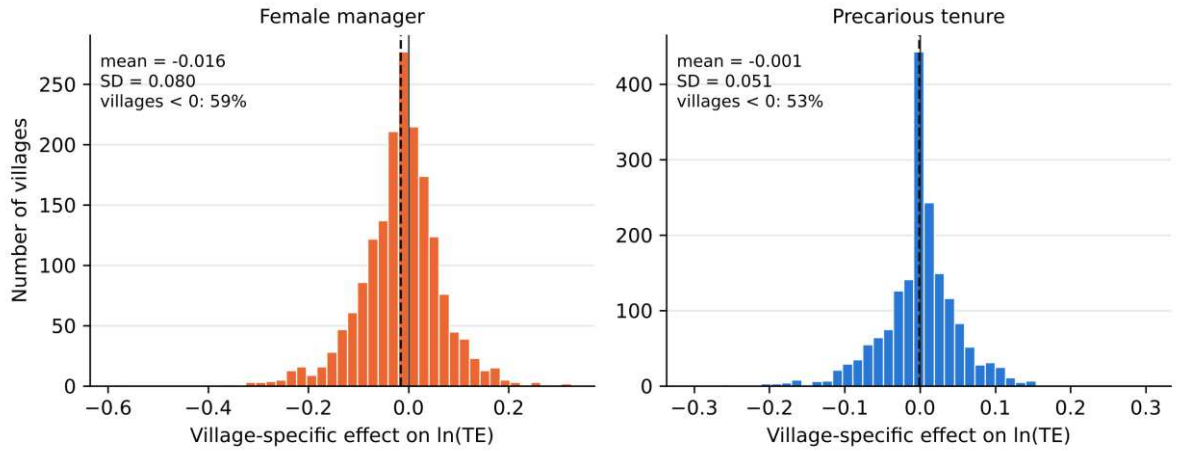

Fig. 5 Distribution of village-specific effects of gender and tenure on ln(TE) (fixed effect + BLUP, model M2). The dashed line marks the mean effect. *Source:* author's calculations.

Regressing the village slopes on village characteristics (Appendix Table A1) confirms this diagnosis. The gender efficiency gap is larger where the share of precarious land is high (−0.0067 per standard deviation, p = 0.035). It is smaller where the labour-to-land ratio is high (+0.0072), perhaps because land scarcity leads every plot, including women's, to be farmed more intensively. The precarious-tenure slope does not depend on any observed characteristic: its genuine heterogeneity (SD 0.090) reflects unmeasured local factors.

6.5. Decomposing the gender productivity gap

Table 5 and Fig. 6 decompose the land productivity gap. The raw gap is 13.2 log points, about 12%. Endowment differences account for almost half of it: fertilizer and seed (32%), other inputs (12%) and manure and SWC (4%). Area and plot quality account for 17%, and technical inefficiency for 27%. Within households, the gap shrinks to 6.0 log points. The share of inputs is higher there (68%), as is that of inefficiency (33%), whereas crop choice works in women's favour (-21%).

The decomposition by tenure status clarifies the role of tenure. The gender gap is almost twice as large on precarious plots (0.189) as on secure plots (0.101). The difference stems mainly from crop choice and location (0.045 versus 0.000) and from other inputs (0.026 versus 0.011), while the inefficiency component is similar (0.034 versus 0.030). Precarious tenure therefore widens the gender gap mainly through the endowments and crops to which women have access on borrowed land, and only marginally through efficiency.

Table 5. Decomposition of the land productivity gap between men's and women's plots

Component	Raw	Share	Within HH	Share	Secure plots	Precarious plots
Total gap in ln(value/ha) (men − women)	0.1318	100%	0.0605	100%	0.1008	0.1889
Area (scale effects)	0.0129	9.8%	0.0096	15.9%	0.0113	0.0145
Mineral fertilizer and seed (quantities)	0.0416	31.6%	0.0281	46.4%	0.0368	0.0476
Manure and SWC	0.0053	4.0%	0.0055	9.2%	0.0049	0.0036
Other inputs (improved seed, traction, labour, herbicide)	0.0159	12.1%	0.0077	12.7%	0.0109	0.0259
Physical plot characteristics	0.0092	7.0%	0.0031	5.2%	0.0053	0.0117
Crop choice and region × season effects	0.0068	5.2%	−0.0129	−21.4%	0.0003	0.0446
Technical inefficiency (E[u|ε])	0.0362	27.4%	0.0200	33.1%	0.0297	0.0340
Random noise	0.0040	3.0%	−0.0007	−1.1%	0.0016	0.0070

Note: decomposition based on the homoscedastic frontier (equation 4). Contributions of inputs and plot characteristics are evaluated at the common frontier coefficients; the "crops and fixed effects" component is the remainder of the deterministic part of the frontier. The within-household decomposition covers household-seasons with both men's and women's plots, with variables centred on household-season means.

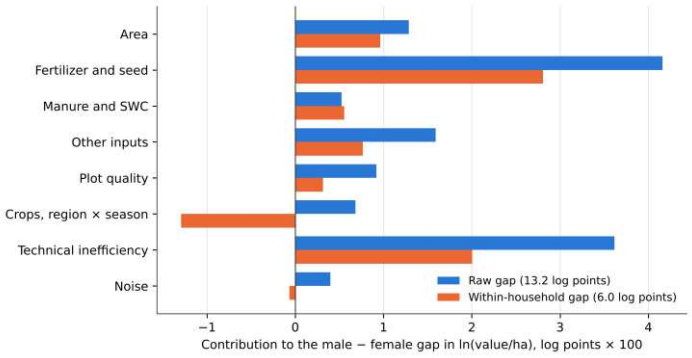

Fig. 6 Contributions to the gender productivity gap (raw and within households). *Source:* author's calculations.

6.6. Robustness

Three checks support these conclusions. **(i)** For cereals only (Table 2, column 2), the female indicator is positive in the inefficiency equation (+0.068, p = 0.066), while precarious tenure has a negative coefficient (−0.049, p = 0.062), which argues against a direct effect of precariousness on inefficiency. **(ii)** The homoscedastic frontier (column 3), used to compute the scores for the multilevel analysis, yields nearly identical elasticities and a mean efficiency of 0.573. We also attempted to estimate the frontier with village fixed effects: the skewness of residuals becomes almost nil and the inefficiency component is no longer identified. A large part of what the pooled frontier attributes to inefficiency is common to plots of the same village, as the multilevel decomposition confirms (30% of the variance of ln(TE) at the village level). This is the cross-sectional analogue of the problem raised by Greene (2005) for panel frontiers: without a way to separate persistent unobserved heterogeneity from inefficiency, pooled estimates overstate the latter. The within-household gender gap does not depend on this choice, since it is identified within households. **(iii)** Scores from the homoscedastic and heteroscedastic frontiers are correlated at 0.999, so the multilevel results do not depend on the choice of first-stage model. The estimates remain subject to the usual limitations of frontiers estimated on survey data: estimated inefficiency absorbs part of the unobserved heterogeneity in soil quality and of measurement error (Gollin & Udry, 2021).

7. Discussion and policy implications

Three lessons emerge. First, the gender productivity gap is primarily an endowment gap. About half of the raw gap reflects quantities of fertilizer, seed and other inputs; technical inefficiency explains only a quarter to a third, and the within-household efficiency gap is about 1.5%. This is consistent with decomposition-based studies (Peterman et al., 2011; Kilic et al., 2015) and with Quisumbing's (1996) early conclusion that women are as efficient as men given equal endowments. The stochastic frontier allows a more precise statement: for equal inputs, women are barely further from the frontier than men.

Second, tenure affects efficiency through context more than through the plot. The precarious status of a plot has no direct effect on efficiency, consistent with complementary work by the author on allocative efficiency (under review): tenure distorts the allocation of land-attached investments more than day-to-day management. In contrast, the gender gap widens in villages where land borrowing is widespread, and the female × precarious double penalty appears clearly in productivity. Women's tenure insecurity thus translates into harder access to inputs and profitable crops on borrowed land rather than into less efficient management.

Third, the gender gap is a matter of social position. It disappears in female-headed households and narrows in villages where female plot management is widespread. This extends Kazianga and Wahhaj (2013), for whom the advantage of the head's fields stems from norms of labour organisation rather than from gender as such. It suggests that "female inefficiency" should be read as lower priority in access to collective labour, equipment and information within male-headed households.

Several implications follow. **(i)** Input-access programmes (fertilizer subsidies, improved seed) should explicitly target women-managed plots, since endowments are the main lever. **(ii)** Securing women's land rights should focus on the stability of their use rights: multi-year plot allocation, written loan agreements as provided for by Law No. 034-2009, and recognition of wives' rights by village land commissions. Formalising ownership that remains in the hands of household heads would do little to close the observed gap. **(iii)** Extension services should target women who are dependants in male-headed households and villages where land borrowing is the norm, where the gap is largest. **(iv)** Female household heads, although technically as efficient as men, are strongly affected by tenure precariousness and should be a priority for securing land loans.

The study has limitations. The EPA does not measure labour time by plot, so family labour is captured only at the household level. Estimated inefficiency may partly reflect unobserved differences in soil quality. Finally, our results describe conditional associations, not the causal effects of a land reform; a staggered roll-out of APFR certificates or written loan agreements would allow such effects to be identified.

8. Conclusion

Using more than 300,000 plot-seasons from Burkina Faso's Permanent Agricultural Survey, this paper combines a one-step stochastic frontier, a four-level hybrid model and a frontier-based decomposition to analyse gender, land tenure and technical efficiency jointly. The gender productivity gap stems first from endowments and secondly from inefficiency. The within-household efficiency gap is small; it widens in villages where land borrowing is widespread and disappears in female-headed households. Precarious tenure barely affects management efficiency as such, but it amplifies the gender gap through context and input access. Closing the gap therefore depends less on improving women's skills than on securing their use rights, improving their access to inputs and changing the norms that organise labour within households.

Future research would benefit from measuring labour by plot and exploiting exogenous variation in land rights.

Statements and declarations

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Data availability : The data analysed in this study are not publicly available. They come from the Permanent Agricultural Survey (Enquête Permanente Agricole, EPA) produced by the Directorate General of Sectoral Studies and Statistics (DGESS) of the Ministry in charge of Agriculture of Burkina Faso. The 2023/24 and 2024/25 rounds are documented in the national microdata catalogue hosted by the National Institute of Statistics and Demography (INSD) : https://microdata.insd.bf/index.php/catalog/83 and https://microdata.insd.bf/index.php/catalog/86 . All rounds used in this study (2014/15 to 2019/20, 2023/24 and 2024/25) are available from DGESS upon request.

Clinical trial number : Not applicable.

Ethics approval : Waived. This study is a secondary analysis of anonymised data from an official statistical survey. The need for ethics approval was waived in accordance with Law No. 036-2021/AN of 6 December 2021 on the organisation and regulation of statistical activities in Burkina Faso.

Consent to participate : Waived, in accordance with Law No. 036-2021/AN of 6 December 2021 on the organisation and regulation of statistical activities in Burkina Faso. The study uses anonymised secondary data, and no new data were collected from human participants.

Consent to publish : Waived, in accordance with Law No. 036-2021/AN of 6 December 2021 on the organisation and regulation of statistical activities in Burkina Faso. The manuscript reports only aggregated results.

Compliance statement : All methods were carried out in accordance with relevant guidelines and regulations, including Law No. 036-2021/AN of 6 December 2021 on the organisation and regulation of statistical activities in Burkina Faso.

Use of AI tools : A generative AI tool (Claude, Anthropic) assisted with data processing, programming of the estimations and language drafting. The author verified all results and text and takes full responsibility for the content.

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Appendix

Table A1. Determinants of village-specific gender and tenure effects (BLUP slopes from model M2)

	Female → ln(TE)	Precarious → ln(TE)	Female → ln(value/ha)	Precarious → ln(value/ha)
Share of precarious plots (z)	−0.0067**	−0.0009	−0.0100**	−0.0011
	(0.0032)	(0.0017)	(0.0042)	(0.0022)
Share of female-managed plots (z)	0.0014	0.0006	0.0013	0.0004
	(0.0037)	(0.0023)	(0.0049)	(0.0031)
Share of documented plots (z)	0.0012	0.0016	−0.0002	0.0025
	(0.0028)	(0.0014)	(0.0036)	(0.0018)
Labour-to-land ratio (z)	0.0072**	0.0018	0.0128***	0.0036
	(0.0033)	(0.0021)	(0.0044)	(0.0028)
Mean ln(1 + TLU) (z)	0.0002	0.0005	−0.0019	−0.0016
	(0.0028)	(0.0019)	(0.0036)	(0.0026)
Share of households in a producer org. (z)	0.0006	0.0018	−0.0035	0.0010
	(0.0029)	(0.0019)	(0.0038)	(0.0025)
Share of female-headed households (z)	0.0021	−0.0017	0.0029	−0.0012
	(0.0027)	(0.0020)	(0.0036)	(0.0026)
Share of cereal plots (z)	−0.0040	0.0007	−0.0033	0.0028
	(0.0029)	(0.0021)	(0.0039)	(0.0028)
Share of schooled managers (z)	0.0001	−0.0013	0.0002	−0.0022
	(0.0029)	(0.0018)	(0.0038)	(0.0024)
Region fixed effects	Yes	Yes	Yes	Yes
Villages	1,780	1,780	1,780	1,780

Note: weighted least squares (weights = number of plots in the village); robust (HC1) standard errors. Explanatory variables standardised. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table A2. Definitions of the main variables

Variable	Definition
Output value	Main-crop production (yield winsorised at p1–p99 by crop and season × area) × 2023–2024 national median price
Area	Measured plot area (ha), ≥ 0.01 ha
Fertilizer	NPK + urea applied (kg), doses capped at the 99.5th percentile
Seed	Main-crop seed quantity (kg)
Female manager	Plot manager is a woman
Precarious tenure	Plot borrowed, rented or ceded without possession rights
Formal document	Title, lease, APFR, cultivation permit, transfer deed or use authorisation
Length of tenure	Season year − year of acquisition
Technical efficiency	$E[\exp(-u)\|\varepsilon]$ (Battese & Coelli, 1988)
Village shares	Shares of village-season plots (excluding the household) that are precarious, documented or managed by women