Productive efficiency in agriculture: Corn Production in Mexico

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Abstract. Using a stochastic production frontier model and data for 2002 from a representative sample of Mexican rural households, in this paper we first study empirically whether or not small and medium farmers produce corn efficiently. The results show that corn production is inefficient, nation-wide and for both commercial and subsistence farmers. Our findings also show that this is even more so for subsistence producers and for the Center and the South-southeast regions of rural Mexico. In addition, we find that subsistence farmers use less productive inputs (seeds and agrochemicals) with respect to commercial farmers. Based on these results, we then apply a regression model to inquire about the factors explaining inefficiency. We get that farmers facing natural disasters, that produce corn for subsistence using diverse seed varieties of the grain in plots with less than 1 hectare and indigenous, are more inefficient than other farmers. The results also indicate that households located in communities with marketing facilities and that have benefited from infrastructural investments, produce corn in a less inefficient manner. The detailed nature of the data used allows us to have results that differentiate rural regions as well as commercial and subsistence corn producers, and hence, to suggest focalized policies for rural development.

1. Introduction

Corn is the major staple in Mexico and its production comes from deeply rooted cultural and economic origins. The cultivation of corn is heterogeneous: traditional or subsistence production (located in the South-Southeast and in parts of the Center of Mexico), and commercial (mainly in the West and North of the country).

Based on data for 2002 obtained from the National Survey to Rural Households in Mexico (or ENHRUM), our study of efficiency uses a stochastic production frontier model. Once this inefficiency indicator is calculated, we estimate the factors that could determine it. We apply the same approaches considering separately subsistence and commercial corn producers.

2. Data and descriptive statistics

ENHRUM is representative of Mexican households (nation-wide and for the country's 5 rural regions), located in towns and villages with 500 to 2499 inhabitants. So, it covers medium size and small agricultural producers, commercial and subsistence. Out of the 1,770 households surveyed, there are 776 observations on corn production, made by 565 households in the five regions. Table 1 presents descriptive statistics of the sample of corn producers and shows that corn production is heterogeneous.

3. Econometric models

Economic or technical efficiency refers to the producer's ability to reach her/his production possibility frontier, characterized by the minimum inputs necessary to obtain a given product. Those who do not reach the frontier are said to be "technologically inefficient", and vice-versa.

The stochastic frontier model (SFM) considers that not all producers are technologically efficient, and with this model it is possible to analyze technical inefficiency in terms of the deviations from the production frontier. Aigner, Novell and Schmith (1977) pointed out that frontier production functions are stochastic due to random variations in the operating environment or to other frontier deviations (see also Greene (2002)).

The stochastic production frontier is determined by its technological structure and by a component of the observed deviations from the production function:

$$\ln Y_i = B_0 + \sum_{n=1}^{N} B_n \ln X_{ni} + e_i$$

$$\ln Y_i = B_0 + \sum_{n=1}^{N} B_n \ln X_{ni} + v_i - u_i ;$$

where the vector of inputs' X_n; n=1…,N belongs to R_N^+; the vector Y of product belongs to R^+; B is the vector of technological parameter to be estimated; and i =1,…,M is the number of producers. In this model of compound error, v_i is the random error term, symmetrical, identical and independently distributed (iid) as N(0, s_v^2) that captures the stochastic perturbation effects, and u_i is the non-negative component attributable to technical inefficiency, independently distributed from v_i.

Table1. Selected Descriptive Statistics of corn production and rural ho useholds. México, 2002						
Variable	South	Center	Center West	North West	North East	National
Sample Mean						
Yield per hectare (mt. Tons.)	0.923	1.226	4.716	7.051	0.880	1.759
Cultivated area (hectares)	1.457	0.897	2.556	6.425	5.692	1.773
Land value (US$/hectare) *	926.5	10,979.2	1,648.9	1,375.2	921.0	4,456.6
Labor force (average per plot)	67.0	40.0	42.2	69.9	27.1	52.0
Tractor hours used in productive cycle	4.0	8.2	30.9	62.6	49.6	13.3
Value of inputs (seed, fertilizer, pesticide, US$)	367.6	969.8	902.0	3572.8	1730.4	806.9
Percentage of households/corn produce rs that…						
Used irrigation	11.45	14.29	15.25	85.00	7.69	14.71
Use fertilizer	66.87	68.42	44.07	90.00	69.23	64.65
Use pesticide	52.41	42.86	31.36	75.00	33.33	45.55
Use improved corn seed varieties	6.93	7.14	19.49	80.00	20.51	11.48
Produced yellow corn	32.23	7.52	1.69	0.00	2.56	16.77
Produced white corn	69.88	75.94	11.02	10.00	7.69	58.32
Used more than one corn variety	37.95	30.45	15.25	0.00	0.00	29.03
Sold their corn production	32.23	22.56	28.81	85.00	20.51	29.16
Sample Mean						
Number of family members	5.1	5.8	6.0	5.5	3.9	5.4
Age of family head (years)	48.2	51.6	56.2	53.3	51.0	50.8
Household head schooling (years)	3.7	3.5	3.6	6.3	4.9	3.7
Family members at working age (%)**	0.69	0.74	0.75	0.77	0.73	0.72
Percentage of households …						
Headed by a female	9.6	8.7	6.8	10.0	2.6	8.5
Indigenous	73.2	27.8	1.7	10.0	10.3	41.9
Receiving remittances	29.2	43.2	61.0	10.0	18.0	37.8
Receiving income transfers (Procampo)	41.3	48.1	50.0	50.0	82.1	49.4
Receiving support from Progresa	64.5	53.8	49.2	0.0	5.1	53.8

* 10.9 Mexican pesos per 1 U.S.A. dollar
** Between 15 and 65 years old
Source: ENHRUM, 2003.

Given that $u_i \geq 0$, $e_i = v_i - u_i$ is asymmetrical, under the assumption that v_i and u_i are independently distributed from X_i, the Maximum Likelihood Method is more effective. Since $e_i = v_i - u_i$, the marginal density function of e_i resulting from integrating u_i on $f(u,e)$ is

$$f(e)=\int_0^{\infty} f(u,e)du = \frac{1}{\sqrt{2\Pi\sigma}}\left[\left\{1-\Phi\frac{e\lambda}{\sigma}\right\}\exp\left\{-\frac{e^2}{2\sigma^2}\right\}\right] = \frac{2}{\sigma}\phi\left(\frac{e}{\sigma}\right)\Phi\left(-\frac{e\lambda}{\sigma}\right)$$

where $\sigma = (\sigma_v^2+\sigma_u^2)$, $\lambda = \lambda = (\sigma_u/\sigma_v)$, $\Phi(.)$ and $\phi(.)$ are the distribution functions of a standard normal and of a density normal, respectively. Using this expression, the function of maximum likelihood (***L***) for a number of M of producers is:

$$\ln L = cte - M \ln \sigma + \sum_i \ln \Phi\left(-\frac{e_i \lambda}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_i e_i^2$$

The maximization of this function gives consistent maximum likelihood estimators of all parameters when the number of producers M tends to infinity. The next step consists in obtaining the technical efficiency estimations for each producer.

Given that $e_i = v_i - u_i$, $f(u|e)$ is distributed as $N^+(\mu, \sigma^{2*})$, the mean serves as a point estimator to calculate the technical inefficiency u_i of each producer:

$$E(u_i \mid e_i) = \mu_i^* + \sigma^* \left[\frac{\phi(-\mu_i^*/\sigma^*)}{1-\Phi(-\mu_i^*/\sigma^*)}\right] = \sigma^* \left[\frac{\phi(e_i \lambda/\sigma)}{1-\Phi(e_i \lambda/\sigma)} - \left(\frac{e_i \lambda}{\sigma}\right)\right]$$

From the estimations of technical inefficiency u_i, we obtain a point estimator for the technical efficiency (ET):

ET = $\exp\{-\hat{u}_i\}$, where $\hat{u}_i$, is the estimation of the inefficiency of the estimators of $E(u_i|e_i)$[1]

4. Results

The econometric analysis consists of two stages. In the first stage we estimate the stochastic frontier production function (SFPF) to evaluate inefficiency in corn production. In the second, we calculate the factors that could explain inefficiency. [2]

The SFPF has as the dependent variable the natural logarithm of the volume of corn production in kilograms (*lnprod*), and as explanatory variables the following inputs (measured in logarithms). Land (*lnsupvxha)*; capital (hours of tractors used *lnmaq)*; labor, total days dedicated for the production of corn (*lnmotot*); and other inputs (*lninsumtot*). [3]

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[1] See Jondrow, J., C. Lovell I. Materov y P. Schmidt (1982).

[2] We eliminated observations where, due to climatic phenomena, total crop loss was reported by surveyed households. This in order to avoid estimation biases, since this phenomena is beyond the farmer's control.

[3] Family and hired labor are assumed to be substitutes. Details in Juarez, M. (2005).

The results of the SFPF are in Table 2. All parameters are significant at a 95% confidence level and the hypothesis of constant return to scale is rejected. Production elasticity with respect to land (*lnsupvxha*) is 0.16, of machinery (*lnmaq*) is 0.05, of labor (*lnmotot*) 0.14 and of agricultural inputs (*lninsumtot*) 0.42. [4]

Table 2. SFPF for Corn, Cobb-Douglas specification						
SFPF mean/normal						
					No.of obs	775
Log likelihood		-1238.6			Wald chi2(4	439.11
					Prob > chi2	0.00
lnprod	**Coeff.**	**Est. error**	**z**	**P>z**	**[95% conf.**	**interval]**
lnsupvxha	0.1617	0.0276	5.86	0.000	0.10757	0.21576
lnmaq	0.0543	0.0136	3.99	0.000	0.02764	0.08097
lnmo	0.1433	0.0466	3.08	0.002	0.05208	0.23461
lninsumtot	0.4161	0.0315	13.23	0.000	0.35445	0.47775
_cons	3.1790	0.2949	10.78	0.000	2.60100	3.75698
/lnsig2v	-0.1053	0.1163	-0.91	0.365	-0.33324	0.12255
/lnsig2u	0.4096	0.2012	2.04	0.042	0.01514	0.80399
sigma_v	0.9487	0.0552			0.84652	1.06319
sigma_u	1.2273	0.1235			1.00760	1.49481
sigma2	2.4062	0.2344			1.94671	2.86564
lambda	1.2936	0.1690			0.96235	1.62492
Probability reason , test of sigma_u =0: chibar2(01) = 15.59 Prob>=chibar2 = 0.000						
Ho: s_u = 0, corn production is efficient						

Source: Own estimations

The null hypothesis is that corn production is efficient, and is rejected at a 95% confidence level (see lower part of Table 2).

The inefficiency term $u_{i,}$ is a random logarithmic variable and a measure of the percentage by which every particular observation cannot reach the production frontier. Results show (Table 3) that the region of Mexico where corn production is more inefficient is the Center (it should increase its production by 108% to reach the production frontier).

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[4] Besides the normal mean distribution for the inefficiency term, the model was estimated with an exponential specification, and the results were similar.

Table 3. Error term u_i of corn production in the SFPF attributed to inefficiency					
Variable	**Obs**	**Mean**	**Stand. Dev**	**Min**	**Max**
South	332	0.98	0.50264	0.29602	4.18039
Center	266	1.08	0.49279	0.40316	4.40948
Centerwest	118	0.85	0.37024	0.37904	2.22864
Northwest	20	0.43	0.25002	0.23233	1.13561
Norteast	39	0.76	0.41154	0.28544	2.13375
National	**775**	**0.97**	**0.48756**	**0.23233**	**4.40948**

Source: Own estimatinos

Using the u_is, in the second stage we calculate the factors that influence inefficiency using a standard linear regression model with robust residuals. We group these factors into three categories (Table 4).

The results are in Table 5. [5] They show that corn producers that had problems related to climatic conditions (*dproblem*) are more inefficient with respect to the rest and the same applies to producers using more than one corn seed variety (*morethan1v*). Farmers with bigger plots (*size*) and producing yellow (*yellow*) corn are less inefficient, whereas farmers producing corn for the market (*dcommer*) are less inefficient than subsistence households. The only significant demographic variable is *dlangua*, showing that indigenous corn producers are more inefficient. Corn producing households located in communities with marketing facilities (*dcommerce*) are less inefficient. Our regional results show that, with respect to the Center of Mexico, the Northeast is less inefficient, followed by the Northwest and the Center-West regions, whereas South-Southeast is as inefficient as the Center.

[5] Due to space and word limitations, in Tables 5, 7 and 9 we only present the explanatory variables that resulted significant at a 95% level or more.

Table 4. Variables used in the regressions to explain inefficiency *	
	Production
dproblem	1 when corn production was affected by climate, 0 otherwise
dcommer	1 if the household sells the corn it produces, 0 if corn is for self -consumption or subsistence
dimprovse	1 if improved corn seed was used for production, 0 otherwise
white	1 if white corn was produced, 0 otherwise
yellow	1 if yellow corn was produced, 0 otherwise
dmorethan1	1 if more than one corn variety of corn was planted, 0 otherwise
size	1 when corn was cultivated in a plot with more than one hectare, 0 otherwise
	Socio-demographic and economic factors of households producing corn
schooling	Years of education of family head
dsex	1 if household heded by a woman, 0 otherwise
dlangua	1 if household head speakes an indigenous language, 0 otherwise
age	Age of household head
availf	Family labor availability (% of family members at working age)
dprocampo **	1 if household receives direct income transfer from PROCAMPO, 0 otherwise
dprogresa ***	1 if household gets supports from PROGRESA, 0 otherwise
dmoneydeliv	1 if household received remittances, 0 otherwise
netfin	Households' net income in pesos coming from governmental programs and formal and informal credit markets
dcommerc	1 if corn produced is sold, 0 otherwise
dbuy	1 if subsistence households bought corn, 0 otherwise
	Town/villages' characteristics
dotherfin	1 when the community has financial institutions (banks, cooperatives, etc.), 0 otherwise
dinfrasinv	1 if , during 1990 -2002, the community was benefited by investments in infrastructure and services
indeservi	Index of 15 services available in the community (communications, transport, electricity, drinking water, etc.)
dorgagric	1 if agricultural organizations exist in the community, 0 otherwise
R1	Region 1, South -Southeast
R2	Region 2, Center
R3	Region 3, Center -west
R4	Region 4, Northwest
R5	Region 5, Northeast

* Variables beginning with "d" are dummies

** PROCAMPO is a governmental program, consisting in direct income transfers to corn producers

*** PROGRESA is a governmental program aimed to reduce poverty

To capture heterogeneity in corn production within regions, we extended the analysis by applying the same econometric methodology for commercial and for subsistence corn producers separately (to avoid auto-selection problems we applied the Heckman (1976) two-step method).

Table 5. Regression model to explain productive inefficiency of corn producers

Regression with robust standard errors					No. of obs	775
					F(19, 755)	13.76
					Prob > F	0.000
					R-square	0.2902
		Robust			Square EMC	0.4162
inefprod	**Coeff.**	**Standard errors**	**t**	**P>t**	**[95% conf. interval]**	
dproblem	0.36657	0.05254	6.98	0.000	0.263421	0.469710
dcommer	-0.16581	0.03559	-4.66	0.000	-0.235679	-0.095941
yellow	-0.12435	0.06169	-2.02	0.044	-0.245464	-0.003238
morethan1v	0.16571	0.05336	3.11	0.002	0.060947	0.270470
size	-0.11539	0.03279	-3.52	0.000	-0.179765	-0.051025
dlangua	0.12150	0.04087	2.97	0.003	0.041273	0.201723
dcommerce	-0.16340	0.02988	-5.47	0.000	-0.222063	-0.104743
dotherfin	0.17679	0.04407	4.01	0.000	0.090283	0.263298
indeservi	0.00558	0.00181	3.08	0.002	0.002027	0.009129
r3	-0.22485	0.05225	-4.30	0.000	-0.327423	-0.122269
r4	-0.29840	0.08554	-3.49	0.001	-0.466335	-0.130471
r5	-0.47839	0.08379	-5.71	0.000	-0.642883	-0.313906
_cons	0.73677	0.10282	7.17	0.000	0.534919	0.938618

Source: Own estimations

3.1 Analysis of commercial corn production

In the SFPF estimation, the Mills ratio (*mill1*) resulted significant at the 95% confidence level. The coefficients for inputs' elasticity are also significant, and differ slightly from those obtained from the total sample, with the exception of land (see Tables 6 and 2). The results also show that commercial corn production has decreasing returns and is produced inefficiently.

Table 7 presents the factors explaining productive inefficiency for commercial corn producers. As for the whole sample, problems related to the climate (*dproblem*) are a factor explaining inefficiency of these producers. Commercial producers cultivating *yellow* corn in bigger plots (*size*) and with other income sources (*netfin*) are less inefficient. However, those benefiting from the governmental program to attend the poor (*dprogresa*) and receiving remittances (*dmoneydel*) are more inefficient. [6]

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[6] The later result could be explained by the fact, found in the literature, that farmers use additional funds for purposes other than the production of corn (Martin and Taylor (2005)).

Table 6. SFPF for Commercial Corn Producers Cobb-Douglas specification SFPF mean/normal						
					No. of obs	226
Log likelihood	-343.66395				Wald chi2(5)	238.12
					Prob > chi2	0.000
lnprod	**Coeff.**	**Error est.**	**z**	**P>z**	**[95% conf. interval]**	
lnsupv xha	0.132038	0.053794	2.45	0.014	0.026605	0.237471
lnmaq	0.079382	0.023558	3.37	0.001	0.033209	0.125554
lnmo	0.148557	0.075348	1.97	0.049	0.000877	0.296237
lninsumtot	0.422180	0.061213	6.9	0.000	0.302205	0.542155
mill1	-1.495344	0.261788	-5.71	0.000	-2.008440	-0.982249
_cons	5.705300	0.786257	7.26	0.000	4.164265	7.246335
/lnsig2v	-0.615791	0.258381	-2.38	0.017	-1.122208	-0.109374
/lnsig2u	0.693648	0.242713	2.86	0.004	0.217940	1.169355
sigma_v	0.734992	0.094954			0.570579	0.946781
sigma_u	1.414567	0.171667			1.115129	1.794412
sigma2	2.541214	0.399739			1.757741	3.324688
lambda	1.924602	0.247921			1.438686	2.410518
Probability reason, test of sigma_u=0: chibar2(01) = 11.02 Prob>=chibar2 = 0.000						
Ho: s_u = 0, corn production is efficient						

Source: Own estimations

Commercial corn producers of the Northwest, Northeast and Center-west are less inefficient than those of the Center and South.

Table 7.Regression Model to explain productive inefficiency of commecial farmers						
Regression with robust standard errors					No. of obs	226
					F(21, 204)	8.680
					Prob > F	0.000
					R-square	0.365
		Robust			Square ECM	0.572
inefcom	**Coeff.**	**Standard errors**	**t**	**P>t**	**[95% conf. interval]**	
dproblem	0.380237	0.168248	2.26	0.025	0.049	0.711986
yellow	-0.516531	0.121713	-4.24	0.000	-0.756500	-0.276562
size	-0.375368	0.095746	-3.92	0.000	-0.564141	-0.186594
schooling	0.041541	0.014152	2.94	0.004	0.013639	0.069444
net fin	-0.000002	0.000001	-2.14	0.033	-0.000004	0.000000
dprogresa	0.174260	0.087906	1.98	0.049	0.000945	0.347575
dmoneydeliv	0.225750	0.108293	2.08	0.038	0.012240	0.439260
r3	-0.283934	0.143048	-1.98	0.048	-0.565967	-0.001901
r4	-0.467210	0.229169	-2.04	0.043	-0.919041	-0.015380
r5	-0.679583	0.214065	-3.17	0.002	-1.101634	-0.257531
_cons	0.578543	0.338176	1.71	0.089	-0.088206	1.245292

Source: Own estimations

3.2 Analysis of corn production for self-consumption

Corn production for subsistence also shows decreasing returns to scale, is inefficient, and there is a selection bias (Table 8).

Table 8. SFPF for Subsistence Corn Producers						
Cobb-Douglas specification						
SFPF mean/normal						
				No. of obs		549
Log likelihood		-825.31157		Wald chi2(5)		229.5
				Prob > chi2		0
lnprod	**Coeff.**	**SD**	**z**	**P>z**	**[95% conf. interval]**	
lnsupvxha	0.104568	0.029092	3.59	0.000	0.047548	0.161588
lnmaq	0.059970	0.014764	4.06	0.000	0.031033	0.088906
lnmo	0.175578	0.050238	3.49	0.000	0.077113	0.274044
lninsumtot	0.285734	0.033602	8.50	0.000	0.219876	0.351592
mill1	-0.598519	0.192921	-3.10	0.002	-0.976637	-0.220401
_cons	4.807207	0.418460	11.49	0.000	3.987041	5.627372
/lnsig2v	-0.460927	0.139094	-3.31	0.001	-0.733546	-0.188308
/lnsig2u	0.464632	0.174844	2.66	0.008	0.121943	0.807320
sigma_v	0.794165	0.055232			0.692967	0.910143
sigma_u	1.261518	0.110285			1.062869	1.497295
sigma2	2.222127	0.227194			1.776835	2.667418
lambda	1.588483	0.153537			1.287556	1.889409
Probability reason, test of sigma_u=0: chibar2(01) = 22.00 Prob>=chibar2 = 0.000						
Ho: s_u = 0, corn production is efficient						

Source: Own estimations

Climate problems (*dproblem*) explain inefficiency and its coefficient is higher than the estimated one for commercial farmers (Table 9, compare with Table 7). Subsistence farmers planting diverse corn seeds (*morethan1v*), buying corn seeds (*dbuy*) and indigenous (*dlangua*) are more inefficient, and those planting white corn (and in bigger plots) are more efficient. Farmers' organizations (*dorgagric*) and access to services (*indiservi*) are related to inefficiency. As commercial corn producers, subsistence farmers located in communities with marketing services (*dcomerce*) are less inefficient. Subsistence farmers receiving government supports and investments (*dinfrasinv*) are less inefficient. Finally, subsistence corn farmers located in the Northeast and the Center-west are less inefficient than those living in the Central region.

Table 9. Regression Model to explain productive inefficiency of subsistence farmers

Regression with robust standard errors					No. of obs	549
					F(22, 526)	8.280
					Prob > F	0.000
					R-square	0.288
		Robust			Square ECM	0.488
inefse lautc	**Coeff.**	**stand. errors**	**t**	**P>t**	**[95% conf.**	**interval]**
dproblem	0.449029	0.067132	6.69	0.000	0.317150	0.580909
white	-0.152336	0.049212	-3.10	0.002	-0.249011	-0.055660
morethan1v	0.235456	0.074641	3.15	0.002	0.088826	0.382086
dbuy	0.119070	0.044886	2.65	0.008	0.030893	0.207247
size	-0.124546	0.047873	-2.60	0.010	-0.218592	-0.030501
dcommerce	-0.119985	0.048478	-2.48	0.014	-0.215220	-0.024751
dorgagric	0.268754	0.084067	3.20	0.001	0.103606	0.433903
indeservi	0.010801	0.002268	4.76	0.000	0.006346	0.015257
dinfras inv	-0.129938	0.046208	-2.81	0.005	-0.220714	-0.039163
dprogresa	-0.143342	0.045374	-3.16	0.002	-0.232478	-0.054206
r3	-0.137869	0.069953	-1.97	0.049	-0.275290	-0.000449
r5	-0.621619	0.114205	-5.44	0.000	-0.845973	-0.397265
_cons	0.686937	0.130572	5.26	0.000	0.430431	0.943444

Source: Own estimations

5. Policy implications

In terms of the production possibility frontier, we found that in general, rural households producing corn are inefficient; but that commercial farmers are less inefficient and apply more productive inputs (seeds and agrochemicals) than subsistence corn producers.

Results of the factors explaining observed inefficiency show that climate is a major event conducting to productive inefficiency. Notwithstanding that climatic unfavorable conditions are exogenous to policy makers, promoting crop insurance could be a way to give income security to rural households.

Producers cultivating several corn varieties and indigenous households are more inefficient, whereas factors reducing inefficiency in corn production are related to market orientation (e.g. production of the crop for the market, access to roads and transportation, and investments in infrastructure). These results indicate that there may be a conflict between the purposes to maintain corn genetic diversity and to promote productive efficiency. One way to solve this dilemma is by monitoring the state of in situ crop genetic diversity and to design focalized policies for maintaining it (see Dyer and Yunez (2003)). Something similar can be said to public investments in rural infrastructure, in the sense that investments should be directed to villages with potential to sell corn or to develop non-farm rural activities. Taking into consideration that the South-southeast is not only where corn is produced in the most inefficient way, but also where rural poverty and indigenous population are more spread-out, our focalized policy suggestion also apply.

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