HERD SIZE AND EFFICIENCY ON MIXED CROP AND LIVESTOCK FARMS : CASE STUDIES OF CHIWESHE AND GOKWE, ZIMBABWE[1]

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This study is based on two 1991 sample surveys, each of ninety farms, in the predominantly arable region of Chiweshe and in the low rainfall area of Gokwe, where animals are more important. The two samples are reasonably representative of the range of conditions found in the communal areas in Zimbabwe. Programming techniques are used to determine the efficiency levels of the farms in each region. The results show that efficiency is positively related to the numbers of both cows and oxen, with only a few farms in Gokwe possibly having too many animals. Farms in Gokwe are on average about two thirds as efficient as those in Chiweshe, which is a measure of the effects of the poorer climate and soils. Non-farm income is also lower, due to lesser opportunities in the more remote region. In both regions, the majority of farms are too small and the estimates suggest that increasing farm size could almost double productivity.

1. INTRODUCTION

The value of animals in the mixed farming systems of Zimbabwe has been the subject of several investigations since Danckwerts (1974) pioneering study, which estimated that the subsistence value of cattle was four times their sales value. The conventional wisdom is that cattle contribute draught power, which increases the cultivated area and reduces labour bottlenecks and drudgery; they provide transportation, which can be an important off-season income source; they provide manure, which increases yields and maintains soil fertility; they increase the protein content of diets by providing milk and occasionally meat; last, they can be a source of cash income, but may often be sold within the community, rather than for slaughter (McIntire et al., 1992). For the Communal Lands, only three to seven percent of herds are sold for slaughter per year, as compared with twenty percent for the Commercial Sector (Rodriguez, 1985). This low off-take is a source of frustration to planners who tend to doubt the efficiency of the subsistence system and see commercialisation as a means of meeting the growing urban demand for livestock products (Eicher & Baker, 1982 and Ndovlu, 1990).

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Animals also meet economic needs not directly related to production, in that they can be an important store of wealth and medium of exchange. The Zimbabwe studies (Sandford, 1982 and Avila, 1985) tend to rank these functions after the productive uses and to accept that while religious and cultural functions matter, they are secondary to the economic factors noted above. The ranking of the economic attributes varies according to the prices used and the assumptions made and so does the estimated value of the animals. The most recent work by Barrett (1992) and Scoones (1992) agrees with Danckwerts (1974) that draught power is of primary importance, followed by milk. Both also find that the value of cattle on-farm exceeds the slaughter value, so herds are not generally too large[2].

This paper investigates the economic value of herds without using prices, such as local hire rates, which in thin markets with few cash transactions may not reflect real values. Nor are assumptions made regarding the number of days that animals are used for ploughing or of milk yields per cow. Instead, the efficiency of the farms is measured solely in terms of ratio of outputs to inputs and then the average efficiencies of farms with different herd sizes are compared. The results for the Chiweshe sample suggest that none of the farms seem to be carrying any surplus animals. For Gokwe, a minority of farmers may have more cattle than is economically efficient, but none have any surplus of oxen.

The relative efficiencies of the farms in the two regions are compared, in order to quantify the productivity disadvantage of Gokwe, the low rainfall area. Finally, decomposing the total efficiency differences into technical and scale efficiency estimates, indicates the extent to which farm size is a constraint to productive efficiency.

The next section provides a brief outline of agricultural conditions in the two regions studied and describes the data. Then, section three outlines the methodology for estimating technical and scale efficiency and section four reports and interprets the results. Section five uses the efficiency scores to compare the productivity of farms with and without cattle. These tests, which are for technical and scale efficiency are supported by econometric estimates of the production relationship, which allow tests of economic efficiency.

2. AGRICULTURAL PRODUCTION IN CHIWESHE AND GOKWE

Zimbabwe is divided into five natural regions that are defined in terms of soil and climate. Regions I, II and III have the best soils and higher, more reliable rainfall, making them more productive than regions IV and V, which have sandy soils with poorer fertility and water retention capacity. The extreme levels of inequality are well stated by Christensen and Stack (1992).

Zimbabwe's one million communal farm households are restricted to half of the total area suited for agricultural production. The other half is occupied by 4,500 large-scale commercial farmers, most of whom are white. To compound this inequality, the communal lands have a much lower agricultural potential; 74% of the communal lands is in natural regions IV and V, and 51% of the commercial farming area is in natural regions I-III.(CSO, 1989). This grossly unequal land distribution is the most fundamental and least tractable of all Zimbabwe's problems. It is also a significant cause of food insecurity in the rural areas.

Within the communal lands, semi-subsistence farming predominates; these areas support 4.3 million people, or 57 per cent of the total population (C.S.O., 1989).

Chiweshe is situated in Natural Region II which is an intensive farming area. Communal farmers occupy 21% of the land; maize is the dominant crop, but cotton, groundnuts and vegetables are also important (Muir, 1994). Rainfall is confined to summer and is moderately high (750-1000mm). This region normally enjoys reliable conditions, rarely experiencing severe dry spells in summer. Gokwe is in Natural Region IV, and is a semi-intensive farming area. Rainfall is fairly low (450-650mm) and is subject to periodic seasonal droughts and severe dry spells during the rainy season.

The sample surveys were conducted in two geographically separate wards of each region, in 1990. Sixty households, out of the six hundred in each ward were randomly selected, giving two samples of one hundred and twenty farms. A quarter of the farms in each region were rejected due to contradictory and/or improbable responses, leaving ninety farms in each sample.

Table 1 gives a summary of the outputs and inputs for the two regional samples, reporting maximum, minimum and mean values (in Zimbabwe $) for crop and animal outputs and non-farm income and for cows, oxen, land (in acres), labour (adults resident in household), fertilizer (50 kg bags) and manure (40 kg cartloads). The dispersion of the variables is indicated by the coefficient of variation, which is a relative measure (the standard deviation divided by the mean). The indicators are consistent with the contrasting farming systems. Chiweshe has higher mean crop output and lower animal output than Gokwe, but the biggest differential is in non-farm income, where Chiweshe is at more than twice the Gokwe level. Relative to Gokwe, Chiweshe has less animals, smaller farms and uses more fertilizer and manure.

The Table shows that farms in Chiweshe are more arable and more intensive than those in Gokwe. The average gross income per cultivated acre in Chiweshe is Z$ 243, as compared with Z$ 92 in Gokwe. Gross income per cow is Z$ 27 in Chiweshe as compared with Z$ 20 in Gokwe. The average gross income from farm sources, per adult household member, is Z$ 288 for Chiweshe and Z$ 152 for Chiweshe. If non-farm income is included, the disparity increases, with Z$ 415 per head in Chiweshe and Z$ 232 in Gokwe. All of these differences are statistically significant at the five percent confidence level. The methodology for measuring efficiency, within and between areas, is described next.

Table 1: Descriptive Statistics for the Sample Farms

	OUTPUTS			INPUTS					
Region	Crops	Animal	Non-Farm	Cows	Oxen	Land	Labour	Fert	Man
Chiweshe (90 farms)									
Max	9696	1795	10867	41	7	18	14	32	74
Min	51	0	0	0	0	1	1	0	0
Mean	1207	218.9	1501.3	8.2	1.78	4.96	7.06	8.36	6.12
C.V.	1.26	1.46	1.42	1.06	1.02	0.63	0.37	0.78	2.08
Gokwe (90 farms)									
Max	5805	1132	8490	39	12	32	23	24	90
Min	51	0	0	0	0	3	3	0	0
Mean	1071	268.7	712.7	13.26	2.89	11.65	8.85	1	2.55
C.V.	0.84	1.01	2.32	0.66	0.71	0.49	0.47	3.31	4.29

3. THE MEASUREMENT OF PRODUCTIVE EFFICIENCY

The model used for measuring farm-level efficiency follows the framework introduced by Farrell (1957) and extended by Fare, Grosskopf and Lovell (1985), to include the decomposition of overall efficiency into measures of technical and scale efficiency. The method, now known as data envelopment analysis (DEA) is non-parametric and deterministic, with the best practice frontier constructed by minimising inputs per unit of output. Then, the efficiency of each farm is measured as a ratio of actual to best practice performance.

There are a number of advantages to this measurement approach. Firstly, it allows the comparison of one farm with a given input-output combination to other farms using inputs in different proportions, neutrally measuring total factor productivity in a multiple input/output framework. Secondly, each input and output can be measured separately in its natural physical units, without the need to apply price or share weights in an aggregation procedure. Thirdly, proportional input decreases translate into reduced costs and any input which is not a constraint on production will be identified as a slack variable. Therefore, the sources of inefficiency can be identified and policies to procure efficient production can take these findings into account. Lastly, the efficiency measurement does not rest on behavioral assumptions, which is useful if producer's objectives differ, are unknown, or not achieved (Grifell-Tatje and Lovell, 1993). These properties are particularly advantageous in applications to agriculture in an environment like the Communal Lands, but on the negative side, the approach tests for technical, not economic efficiency. It is necessary to supplement the DEA with econometric estimation of the production function to overcome this deficiency.

In Figure 1, the efficiency frontier is the unit isoquant, which is determined by the linear combination of just two efficient farms, B and C, and is labelled Y^*. The efficiency of a farm such as A, that is not on the frontier, is measured by the ratio OD/OA, since OD is the vector representing the lowest mix of inputs which farm A could use and still reach the isoquant, using its own factor combination.

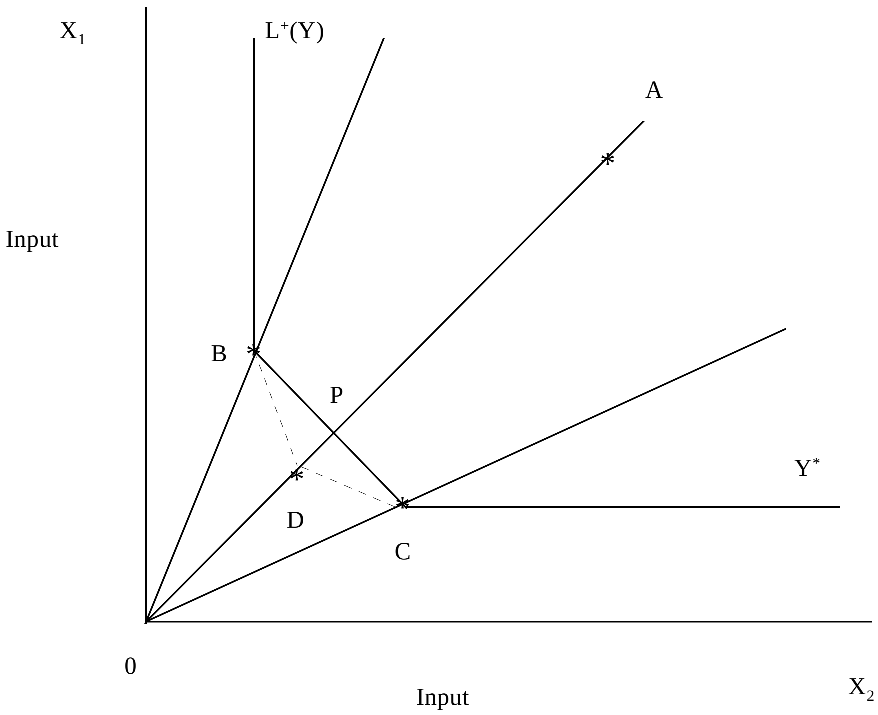

Figure 1: Farrell efficiency measurement

The efficiency measures which result from this analysis are reported in the next section. This is an assessment of total efficiency, and includes both technical and scale effects Since the efficiency effects of farm size are relevant to the land reform debate Bratton, 1994, Roth, 1994), the effects of farm size are separated from technical efficiency. Figure 2 shows this decomposition. Following Fare et al (1985), the relationship between total efficiency, F(y,x), pure technical efficiency, T(y,x) and scale efficiency S(y,x) is

$$Fi(y,x)= Ti(y,x).Si(y,x)$$

The left hand term is the total efficiency level, explained above, and now $T_i(y,x)$ is calculated as a programming problem in which constant returns to scale (CRTS) is not imposed, so that technical efficiency is measured independently of scale effects. In Figure 2, the constant returns to scale (CRTS) technology is denoted by the linear total product curve, OP, from the origin, through the efficient production units B and C. Units A and D, in this example, are inefficient as they are below the CRTS frontier. When non-constant returns to scale are allowed for, the frontier is concave and envelopes the data more closely. Thus, farm A is scale inefficient by OX/OX^*, due to being too small, but is technically efficient. Farm D is similarly technically efficient, but is too large and is scale inefficient by OX^{**}/OX^{***}. Finally, farm E is technically inefficient by OX^*/OX^{**} and scale inefficient by OX/OX^*, giving a total level of inefficiency, relative to the CRTS frontier, of OX/OX^{**}.

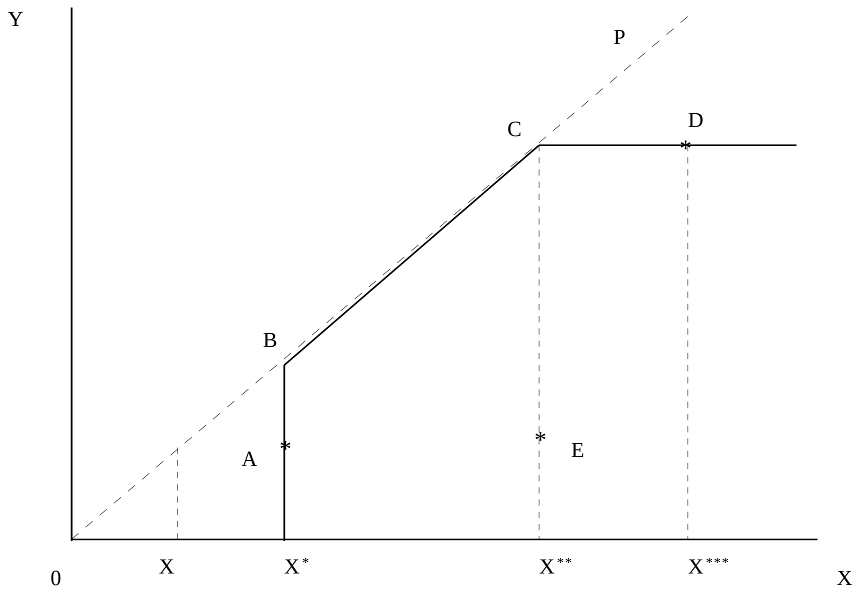

Figure 2: Decomposition of technical and scale efficiency

4. TOTAL, TECHNICAL AND SCALE EFFICIENCY: RESULTS

The DEA analysis was applied to the two regions separately and then to the pooled data set of the two regions together. Table 2 shows the results for the three output, six input case, with the variables defined as in Table 1. The results are not particularly sensitive to the level of aggregation. Thus, using three separate outputs, or aggregating them to a single measure of total output leads to similar efficiency scores. The outcomes are more affected by the exclusion of weak variables, such as manure, which is included since Smith (1993) has shown that it is better to err on the side of including possibly irrelevant variables than to exclude one that is relevant.

Table 2: Summary of Efficiencies by Region, Using Total Income

	Gokwe (90 farms)	Chiweshe (90 farms)

	Gokwe (90 farms)			Chiweshe (90 farms)		
Efficiency	Total	Technical	Scale	Total	Technical	Scale
Maximum	1.000	1.000	1.000	1.000	1.000	1.000
Minimum	0.052	0.251	0.076	0.075	0.264	0.075
Mean	0.373	0.675	0.521	0.458	0.820	0.586
C.V.	0.820	0.363	0.561	0.655	0.310	0.547
Farms 100% Efficient	9	18	9	11	56	11

The total efficiency frontier for Gokwe is defined by nine farms and for Chiweshe eleven farms are on the frontier. The efficiency levels are measured relative to the frontier, with the farms on the frontier having a level of 1.00. The mean efficiency levels of 0.373 for Gokwe and 0.458 for Chiweshe are an indication more of the importance of unmeasured physical characteristics, such as soil and access to water, rather than being attributable to factors like farm management. The greater dispersion of efficiencies in Gokwe is confirmed by the greater coefficient of variation (0.820 relative to 0.655).

A limitation of the DEA approach is that little can be said about the characteristics of the efficient farms. Whereas production function analysis find a line of best fit and thus identifies the characteristics of the "average" farm, the DEA frontiers in the figures are defined by the outliers. Thus, if in Figure 1, X_1 were animals and X_2 were all other inputs, there is a strong tendency for the frontier to include a farm that has no animals, as this unit will have minimised the use of that one input. Similarly, if X_1 were traditional inputs and X_2 were modern inputs (fertilizer, in this case), there will tend to be traditional farms, that use no fertilizer and fertilizer-using farms on the frontier.[3] Since this is true for each dimension, with six inputs there will often be six efficient farms such as units B and C in the Figure, plus some intermediate cases. Thus, if D were a farm and maintained the same factor ratio but used slightly less inputs, it would also appear on the frontier. The last line of Table 2 shows that there are three farms of this sort in Gokwe and five in Chiweshe, in addition to the six farms that minimise the use of a particular input.

Thus, because of the nature of the frontier, there is little of any relevance to policy in the characteristics of the efficient farms, so these are not reported. However, DEA does allow scale economies to be identified at the level of the individual farm, so we exploit this advantage of the technique and concentrate on the issue of farm size. The total efficiencies can be decomposed into technical efficiency and scale efficiency, as explained above. In the Gokwe sample eighteen of the farms (20%) appear to be technically efficient and the mean level of technical efficiency is a respectable 67.5%, but only nine farms (10%) are scale efficient. Since the average level of scale efficiency is only just over 50%, increasing farm size to the required level could be expected to practically double efficiency. For the Chiweshe sample, the decomposition shows that almost two-thirds (56) of the farms are technically efficient and the mean technical efficiency level is 82%, but scale causes almost as much of an efficiency loss as in Gokwe.

The farm size problem is confirmed by the tests for increasing, decreasing and constant returns to scale. These are reported in the Appendix, along with the total, technical and scale efficiencies, at the individual farm level. For Gokwe, eighty farms exhibited increasing returns (meaning they are too small, like farm A, in Figure 2), nine had constant returns (indicating that they are scale efficient, like farms B and C in the Figure) and only one farm showed decreasing returns (too large, like D in the Figure). In Chiweshe, the area with greater population pressure on the land, seventy-nine farms were too small, eleven scale efficient and none were too large.

The efficiencies reported above are all relative to the regional efficiency frontiers. That is, the efficiency levels of the Gokwe farms are calculated on the basis of a frontier constructed from the best-practice farms in Gokwe only. Pooling the data for Chiweshe and Gokwe allows comparisons that determine the relative efficiencies of the two regions. The results of this exercise are reported in Table 3.

Table 3: Summary of DEA Results for the Pooled Sample

	Gokwe (90 farms)			Chiweshe (90 farms)		
Efficiency	Total	Technical	Scale	Total	Technical	Scale
Mean	0.198	0.443	0.446	0.448	0.822	0.545
Farms 100% Efficient	5	8	5	10	45	10

Comparing these results with those in Table 2 shows that fewer farms lie on the combined efficiency frontier than on the separate regional frontiers. This is inevitable, since as the sample size is increased by pooling, a farm's efficiency can only decrease, as its comparison set is augmented by new observations (Nunamaker, 1985).

The efficient farms are thus a subset of the regionally efficient units, with only five farms in Gokwe and ten in Chiweshe defining the frontier. In terms of Figure 1, suppose that X_1 is a traditional input, such as land and X_2 is an input used for intensification, such as chemical fertilizers. The four Gokwe farms that were on the regional frontier and are not on the pooled frontier, were intensive producers (by local standards), using fertilizer inputs. These are dominated by the more efficient intensive farms in Chiweshe. Conversely, one of the low input farms in Chiweshe that was on the frontier, has been replaced by more efficient low input farms in Gokwe.

Thus, almost half the previously efficient Gokwe farms are now off the frontier and the average efficiency level of the Gokwe farms falls to 0.198, when measured relative to the combined frontier. The Chiweshe results, by comparison, change very little. Comparing the total efficiency levels of the two samples suggests that the Gokwe farms achieve only about 44% of the efficiency of the Chiweshe sample (.198/.448). This difference must be largely attributable to the poorer soil quality and lower rainfall. However, Table 1 indicated that part of the disparity resulted from the inequality in non-farm incomes. If the pooling test is performed with only crop and livestock outputs, the mean efficiency for Chiweshe is almost unchanged, at 0.450 and the Gokwe figure is 0.289. This suggests that, net of non-farm income, Gokwe is about two-thirds as efficient in terms of agricultural productivity.

5. HERD SIZE AND EFFICIENCY

The debate in Zimbabwe on herd size has centred on the low off-take of cattle from the communal lands, which has restricted their contribution to feeding the urban population, and the possibility of environmental damage due to over-stocking, versus the more recent emphasis on the many contributions of cattle in mixed farming systems. It is clear from previous studies and from the data used here that there is a correlation between low incomes and lack of cattle. However, this does not determine the direction of causality or explain the contribution of cattle. The DEA efficiency results allow a simple test of the value of cattle in the farming systems studied here. Firstly, if farms without animals have lower average efficiencies than those that have cattle, it is possible to infer that cattle do generally improve performance. If the farms are divided according to herd size and the efficiency of the farms with the largest herds is not lower than it is for those with less cattle, the inference is that no farmers are carrying too much stock. Indeed, such a result would suggest a shortage, in that the value of the cattle within the system, in terms of final products like milk and meat, and intermediate inputs such as draught power and manure, is increasing with herd size.

Table 4 reports the results, calculated from the total efficiencies in the Appendix. Since the expectation is that oxen are used for power and transportation, while cows provide milk and calves, the two are separately reported. For Chiweshe, the farms with oxen appear to be considerably more efficient than those without (0.44 against 0.33) and the same is true for households with and without cows. These results, with the sample sizes stated in brackets, are statistically significant. The appropriate test (Banker, 1993) for differences in DEA efficiencies between two groups is an F test of the ratio of the sum of the *squares* of the inefficiencies, each divided by the sample size. For the oxen, the value of the test statistic is 1.66, against a 95% confidence level critical ($F_{35, 55}$) value of 1.64. The inference is that farms with oxen are more efficient than those without *for the parent population from which the sample was drawn*. The same could be claimed for the with and without cows result, although it actually fails the test by an equally narrow margin, of 0.02 (1.63 against 1.65).

Table 4: Total Efficiency Levels, by Herd Size

	Oxen		Cows		
Number	Chiweshe	Gokwe	Number	Chiweshe	Gokwe
Without	0.33 (35)	0.94 (9)	Without	0.35 (30)	0.96 (5)
With	0.44 (55)	0.44 (81)	With	0.42 (60)	0.46 (85)
One	0.54 (8)	0.45 (14)	One to Nine	0.40 (25)	0.49 (39)
Two	0.36 (18)	0.49 (22)	Ten to Nineteen	0.43 (26)	0.46 (30)
Three	0.44 (8)	0.34 (9)	Twenty and Over	0.50 (9)	0.36 (16)
Four	0.46 (15)	0.38 (22)			
Over Four	0.50 (6)	0.46 (14)			

The mean efficiencies for the different groups are followed by the numbers of farms in the group, shown in brackets.

Tests comparing those with animals to those without are not applicable to Gokwe, where almost all farms have animals. The small minority that have no animals did have high efficiency scores as a result of non-farm activities, such as trading. On the negative side, these tests indicate that for all the other comparisons, with discrete numbers of animals, the samples are too small to support any inferences concerning the parent population. The most that can be claimed is that the larger differences, that are also based on larger samples, are significant, at low confidence levels, only if the total sample is regarded as being an accurate representation of the parent population. With this limitation in mind, the results in Table 4 can be considered.

Thus, the groups with one or three oxen in Chiweshe are too small (eight farms) to be meaningful. The low numbers result from the fact that oxen are better worked in teams of two or four[4]. In Chiweshe, four oxen farms are rather more efficient than those with only two animals. On this issue, Tembo and Elliot (1987) estimated that a span of four oxen was required to provide sufficient power, whereas Goe (1983) suggested that two are adequate. The difference is not significant and anyway seems to depend on the type of farming system. Thus, the efficiency results for the more intensive region are reversed for Gokwe, where there is a similar efficiency differential in favour of two oxen farms. In both regions though, it seems unlikely that there is a surplus of draught power, since the small number of farms with over four oxen are highly efficient, perhaps because they plough for others or are involved in transportation activities.

The situation with cows is little different in Chiweshe, where herd size and efficiency appears to be positively correlated, though the efficiency differences are very small. Still, the minority of nine farms with more than twenty cows were the most efficient group. For Gokwe, the sixteen farms with more than twenty cows appear to be less efficient than those with less than twenty, but again, the statistical significance of the difference is very low. This is weak evidence that cattle are kept beyond the efficient level. In fact, interviews with farmers showed that 14% of households did have more cattle than they needed to produce intermediate products[5]. The sales and slaughters from this group were sufficient to give the Gokwe sample an off-take of about 6 percent, which is well above the average for the Communal Lands. However, the animals were disposed of within the community, rather than sold to the Cold Storage Commission (CSC). This suggests that CSC data on rates of off-take in the Communal Areas will grossly under-estimate the actual slaughter rates. The usefulness of the DEA-based tests is limited by the levels of statistical significance and the fact that the DEA assesses only technical efficiency. The alternative, which is econometric estimation of the production relationships, allows simple tests of economic efficiency, but raises other difficulties[6]. The most consistent results, from a simple log-linear (Cobb Douglas) functional form, are reported in Table 5.

Table 5: Production Function Estimation

Chiweshe, 90 Farms: Dependent Variable Total Output, Adjusted R^2 = 0.88							
Variable	Cows	Oxen	Land	Labour	Fertilizer	Manure	DEA Index
	0.093 (6.4)	0.112 (8.9)	0.261 (4.4)	0.379 (6.6)	0.010 (1.5)	-0.006 (-1.3)	0.21 (1.9)
Gokwe, 90 Farms: Dependent Variable Total Output, Adjusted R^2 = 0.82							
	0.094 (6.7)	0.090 (7.3)	0.248 (4.4)	0.449 (10.9)	0.011 (1.8)	-0.007 (-1.0)	0.49(3.7)

The estimated coefficients are followed by the t - statistics, in brackets.

Both equations have adjusted R^2s that are unusually high for cross section data. This is caused by including the DEA efficiencies as an explanatory variable, to take account of the differences in physical characteristics, managerial skills and other missing variables. This adjustment follows the pioneering work of Hoch (1955) and Mundlak (1961) who used farm-specific dummy variables to account for unobserved inter-farm differences in pooled cross section and time series data. The coefficients of the DEA efficiency variable suggest that variations in land quality are more important in Gokwe. The constant are not reported, as they provide no useful information. The other estimated coefficients may be interpreted as output elasticities, or factor shares, and all are in the correct range. Reasonably enough, labour and land have the largest effects, followed by animals, while fertilizer and manure make only small contributions to output. The two areas appear to be very similar. For both, labour is most important, followed by land and then the animals, with fertilizer playing a very minor role and manure not making a significant contribution. All the major variables are significant at the 99% confidence level and fertilizer at 95% for Gokwe and 90% for Chiweshe.

While the regression results serve to test the data and show that the animal inputs are significant, it is not clear that marginal analysis is appropriate for evaluating the allocative efficiency of the system. The elasticities are in value terms, so if they are multiplied by the average value of the output divided by the average value of the inputs (from Table 1), the value marginal products can be retrieved very easily. This calculation gives a value for the marginal ox in Chiweshe of Z$ 184 per year. This would suggest a shortage, since the animal would cost about Z$400 and must be expected to function for several years. The Gokwe figure for oxen is Z$ 63, which is close to equilibrium, in the sense that the animal would have to serve for perhaps eight years to cover its cost (allowing for discounting). Thus the regression results support the DEA findings on the value of oxen, in that there is no surplus of animals.

On the other hand, the marginal cow in Chiweshe has a value of only Z$ 31 per annum, so it would have to serve for over twelve years to cover its cost. The Gokwe value of Z$ 15 per cow does suggest an excess of animals, if marginal analysis is applied to this type of system. Certainly, past investigators have used average, rather than marginal, products. For instance, the calculations on the value of draught animals in the work of Barrett (1992) and Scoones (1992) are for the average animal, rather than at the margin. The equivalent figures here are easily calculated from Table 1 and are compared with the marginal figures in Table 6. If total income is divided by the number of oxen, the annual average value product in Chiweshe is Z$ 1645 and in Gokwe the equivalent figure is Z$ 710. Even if non-farm income is excluded (and it is partly income for using animals for transportation etc.), the annual value of the average ox is still Z$ 801 in Chiweshe and Z$ 464 in Gokwe.

Table 6: Marginal and Average Values of Oxen and Cows

	Cows				Oxen			
	VAP	VMP	PRICE	IRR	VAP	VMP	PRICE	IRR
Chiweshe	1645	184	Ox 400 Calf 200	44%	357	31	Cow 420 Calf 225	3.5% 12.5%
Gokwe	710	63	Ox 400 Calf 200	10%	155	15	Cow 420 Calf 225	-1.7% 4.5%

Whereas the marginal cow appeared to have a fairly low value in both areas, the total income calculation gives an annual average value of Z$ 357 for Chiweshe and Z$ 155 for Gokwe. Even if non-farm income is excluded, the figures are Z$ 174 and Z$ 101. Thus, the value of the average animal is high enough to suggest a shortage of animals in all cases, but it is the marginal values that are relevant to economic decision-making.

Testing the marginal results for oxen is hardly necessary, but if a working life of eight years is assumed, with a terminal value of Z$ 150 for the meat in the next year, the internal rate of return for an ox in Chiweshe is 44% and in Gokwe 10%, even if the purchase price is taken to be that of a mature animal.[7] The cows were culled at an average of fifteen years, so if a Chiweshe cow cost Z$ 420 and yielded Z$ 31 for fourteen years, before being sold for meat at Z$ 140, the IRR is 3.5%. If the purchase price is taken to be that of a calf, then the IRR rises to 12.5%. For Gokwe, if the value of a mature animal is used as the purchase price, the IRR is -1.7%, rising to 4.5% if the price of a calf is thought to be appropriate for the calculation. Thus, the marginal analysis based on econometric estimation supports the DEA results, showing that only in the case of cows in Gokwe is there even weak evidence of over-stocking, as judged from the viewpoint of technical and economic efficiency.

6 CONCLUSIONS

This paper uses recent farm-level survey data to study the productive efficiency on farmers in the Communal Lands, in an average rainfall year. Non-parametric techniques allow estimation of total productive efficiency in the absence of prices, or when price data is too unreliable or distorted to be useful. The efficiency levels calculated suggest firstly that the farms in both regions are too small. Secondly, the low rainfall area appears to be about two thirds as efficient as the more favoured area. This is a measure of the effect of the physical environment on agricultural productivity, but the survey shows that this is exacerbated by considerably lower non-farm incomes. Comparing the efficiencies of farms with different size herds suggests that there is a shortage of both oxen and cows in Chiweshe and a shortage of oxen in Gokwe. However, the efficiency tests, evaluation of the variable slacks in the programming problem and econometric estimation of the production function all show that a minority of farms in Gokwe may have an excess of cows. This is in agreement with the interviews conducted with the farmers and accounts for the off-take of animals in Gokwe, which is higher than the average for the Communal Areas.

1. The survey data used in this paper is from Muchena's University of Reading Ph.D thesis. We thank Steve Wiggins, who directd the thesis, for comments and the Development Bank of Southern Africa for financial support.

2. The policy problem of over-grazing of communally-owned land (addressed by Vink and van Zyl, 1992) is a separate issue.

3. See the discussion of the pooled sample results which follow below.

4. But in Chibi South, Collinson (1987) found that cows were being used for ploughing.

5. The DEA measures efficiency, but as Ali and Seiford (1993) explain, this problem should be viewed as the first stage of a two stage model, in which the slacks are also examined. If a variable is slack it is not acting as a constraint on production in the programming problem. The slacks in this study were messy and added little, but for

Gokwe cattle was slack in 14% of the cases. That this result is exactly the same as the interviews indicated is pure serendipity.

6. For instance, the samples are too small to divide up, so all the results are for the average of all the farms in the sample.

7. All the prices are averages of the prices received by farmers in 1991.

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APPENDIX

TABLE 1: GOKWE: TECHNICAL, TOTAL AND SCALE EFFICIENCY, AND RETURNS TO SCALE (RTS)

FARM	TECH	TOTAL	SCALE	RTS	FARM	TECH	TOTAL	SCALE	RTS
1	0.696	0.190	0.273	IRS	46	0.325	0.110	0.340	IRS
2	0.538	0.354	0.658	IRS	47	0.251	0.180	0.719	IRS
3	0.659	0.613	0.931	IRS	48	0.923	0.235	0.254	IRS
4	0.464	0.408	0.880	IRS	49	1.000	1.000	1.000	CRS
5	1.000	0.405	0.405	IRS	50	0.333	0.124	0.372	IRS
6	0.726	0.625	0.861	IRS	51	0.374	0.158	0.423	IRS
7	0.414	0.214	0.517	IRS	52	1.000	1.000	1.000	CRS
8	0.644	0.080	0.124	IRS	53	0.558	0.482	0.864	IRS
9	0.538	0.138	0.256	IRS	54	0.386	0.313	0.811	IRS
10	1.000	0.213	0.213	IRS	55	0.781	0.287	0.368	IRS
11	0.390	0.118	0.303	IRS	56	0.880	0.877	0.997	IRS
12	1.000	1.000	1.000	CRS	57	0.491	0.256	0.521	IRS
13	1.000	1.000	1.000	CRS	58	1.000	1.000	1.000	CRS
14	0.400	0.271	0.677	IRS	59	0.294	0.165	0.561	IRS
15	0.984	0.879	0.893	DRS	60	0.870	0.481	0.553	IRS
16	0.916	0.370	0.404	IRS	61	0.387	0.224	0.579	IRS
17	0.348	0.151	0.434	IRS	62	0.957	0.462	0.483	IRS
18	0.374	0.140	0.375	IRS	63	0.658	0.630	0.957	IRS
19	0.702	0.099	0.141	IRS	64	0.593	0.052	0.088	IRS
20	1.000	1.000	1.000	CRS	65	0.594	0.356	0.599	IRS
21	0.341	0.150	0.440	IRS	66	1.000	0.466	0.466	IRS
22	0.423	0.134	0.318	IRS	67	0.543	0.175	0.323	IRS
23	0.641	0.195	0.304	IRS	68	0.557	0.123	0.222	IRS
24	0.317	0.119	0.377	IRS	69	1.000	1.000	1.000	CRS
25	1.000	0.239	0.239	IRS	70	0.798	0.157	0.196	IRS
26	0.622	0.373	0.601	IRS	71	0.411	0.181	0.439	IRS
27	0.579	0.574	0.991	DRS	72	0.743	0.135	0.182	IRS
28	0.943	0.804	0.852	DRS	73	0.713	0.420	0.588	IRS
29	0.894	0.128	0.143	IRS	74	0.567	0.085	0.150	IRS
30	1.000	1.000	1.000	CRS	75	0.968	0.122	0.126	IRS
31	0.967	0.074	0.076	IRS	76	1.000	0.727	0.727	IRS
32	1.000	0.876	0.876	IRS	77	1.000	0.841	0.841	IRS
33	0.668	0.229	0.343	IRS	78	0.808	0.223	0.276	IRS
34	0.387	0.198	0.511	IRS	79	0.469	0.091	0.195	IRS
35	0.601	0.173	0.289	IRS	80	0.383	0.214	0.560	IRS
36	0.966	0.074	0.077	IRS	81	0.515	0.145	0.281	IRS
37	0.859	0.434	0.505	IRS	82	0.739	0.209	0.283	IRS
38	0.460	0.117	0.255	IRS	83	1.000	1.000	1.000	CRS
39	0.419	0.110	0.262	IRS	84	0.476	0.172	0.362	IRS
40	0.427	0.068	0.160	IRS	85	0.475	0.224	0.471	IRS
41	0.550	0.223	0.406	IRS	86	0.857	0.255	0.298	IRS
42	1.000	0.987	0.987	DRS	87	0.357	0.251	0.703	IRS
43	0.484	0.092	0.190	IRS	88	0.666	0.371	0.557	IRS
44	0.879	0.707	0.804	IRS	89	0.460	0.256	0.557	IRS
45	1.000	0.924	0.924	DRS	90	0.380	0.112	0.300	IRS
SCALE	IRS 76	CRS 9	DRS 5		MEAN	0.675	0.373	0.521	

DRS = Decreasing Returns, CRS = Constant Returns and IRS = Increasing Returns to Scale

TABLE 2: CHIWESHE: TECHNICAL, TOTAL AND SCALE EFFICIENCY, AND RETURNS TO SCALE

FARM	TECH	TOTAL	SCALE	RTS	FARM	TECH	TOTAL	SCALE	RTS
1	1.000	1.000	1.000	CRS	46	1.000	0.233	0.233	IRS
2	1.000	0.143	0.143	IRS	47	0.540	0.481	0.891	IRS
3	1.000	1.000	1.000	CRS	48	1.000	0.204	0.204	IRS
4	1.000	1.000	1.000	CRS	49	0.475	0.450	0.948	IRS
5	1.000	1.000	1.000	CRS	50	1.000	0.675	0.675	IRS
6	1.000	0.205	0.205	IRS	51	1.000	0.090	0.090	IRS
7	1.000	0.268	0.268	IRS	52	0.433	0.254	0.587	IRS
8	1.000	1.000	1.000	CRS	53	0.444	0.382	0.861	IRS
9	1.000	0.594	0.594	IRS	54	1.000	1.000	1.000	CRS
10	1.000	0.217	0.217	IRS	55	1.000	1.000	1.000	CRS
11	0.528	0.187	0.354	IRS	56	0.565	0.446	0.788	IRS
12	0.465	0.264	0.568	IRS	57	0.416	0.263	0.632	IRS
13	1.000	0.307	0.307	IRS	58	0.362	0.197	0.545	IRS
14	1.000	0.618	0.618	IRS	59	0.332	0.253	0.763	IRS
15	1.000	0.075	0.075	IRS	60	1.000	0.908	0.908	IRS
16	0.406	0.375	0.925	IRS	61	1.000	0.348	0.348	IRS
17	0.363	0.120	0.331	IRS	62	0.595	0.537	0.902	IRS
18	1.000	0.095	0.095	IRS	63	0.529	0.464	0.877	IRS
19	1.000	0.335	0.335	IRS	64	1.000	0.177	0.177	IRS
20	1.000	0.592	0.592	IRS	65	1.000	0.340	0.340	IRS
21	1.000	0.894	0.894	IRS	66	0.654	0.651	0.995	IRS
22	1.000	0.302	0.302	IRS	67	1.000	0.337	0.337	IRS
23	1.000	1.000	1.000	CRS	68	0.506	0.275	0.543	IRS
24	1.000	0.530	0.530	IRS	69	1.000	0.962	0.962	IRS
25	1.000	0.701	0.701	IRS	70	0.590	0.506	0.857	IRS
26	1.000	0.902	0.902	IRS	71	0.320	0.192	0.599	IRS
27	1.000	0.148	0.148	IRS	72	0.369	0.248	0.672	IRS
28	1.000	0.302	0.302	IRS	73	0.374	0.328	0.876	IRS
29	1.000	0.115	0.115	IRS	74	0.264	0.223	0.843	IRS
30	1.000	0.181	0.181	IRS	75	0.484	0.478	0.988	IRS
31	0.771	0.743	0.964	IRS	76	0.524	0.368	0.704	IRS
32	1.000	0.345	0.345	IRS	77	1.000	0.209	0.209	IRS
33	1.000	0.082	0.082	IRS	78	0.843	0.807	0.958	IRS
34	0.791	0.764	0.966	IRS	79	1.000	0.270	0.270	IRS
35	0.926	0.925	0.998	IRS	80	1.000	0.188	0.188	IRS
36	1.000	1.000	1.000	CRS	81	0.934	0.785	0.840	IRS
37	1.000	1.000	1.000	CRS	82	1.000	0.167	0.167	IRS
38	0.389	0.165	0.424	IRS	83	1.000	1.000	1.000	CRS
39	1.000	0.445	0.445	IRS	84	1.000	0.122	0.122	IRS
40	0.582	0.542	0.931	IRS	85	1.000	0.838	0.838	IRS
41	0.448	0.224	0.499	IRS	86	1.000	0.310	0.310	IRS
42	1.000	0.250	0.250	IRS	87	1.000	0.119	0.119	IRS
43	0.350	0.182	0.520	IRS	88	1.000	0.128	0.128	IRS
44	0.508	0.278	0.547	IRS	89	1.000	0.473	0.473	IRS
45	0.707	0.606	0.856	IRS	90	1.000	0.484	0.484	IRS

SCALE	IRS 79	CRS 11	DRS 0		MEAN	0.820	0.458	0.586	

DRS = Decreasing Returns, CRS = Constant Returns and IRS = Increasing Returns to Scale