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Productivity benchmarking of free-range sheep operations: Technical efficiency, correlates of productivity and dominant technology variants for Laingsburg, South Africa

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Abstract

Data envelopment analysis (DEA) was used to benchmark extensive sheep operations in Laingsburg in the Central Karoo, South Africa, with data from the 2012 production season. An input oriented variable returns to scale frontier identified twelve efficient firms, and nine more that are technically efficient but not scale efficient. The top third's overall efficiency score was 0.999. For the bottom third the average efficiency score was just 0.346, which indicates that there is substantial room for improvement amongst bottom third producers in this production system. Overall efficiency was correlated with stocking density, flock size, unit production cost and profitability, cumulative family experience of farming and the use of family labour, but not with farm size, breed choice or any proxy for individual experience or ability. Predation rates in particular were uncorrelated with productivity scores and reproductive performance was only weakly correlated with it. While most farms could theoretically improve their efficiency by intensifying their operations, a closer analysis of best practice firms revealed a spectrum of optimal intensities including the possibility of restoring rangelands by deliberate understocking. Grazing strategy and the degree of labour self-sufficiency emerged as the key determinants of optimal intensity.

Introduction

Commercial sheep farming in the Karoo region of South Africa is in trouble. An index number accounting analysis of total factor productivity covering the period 1952 to 2002 shows no technical progress in any of the four sheep grazing districts of the Western Cape Province despite strong growth in horticulture in some places (Conradie *et al.*, 2009). A cost-price squeeze that results from falling output prices and rapidly rising factor costs has been identified as the underlying problem (Conradie *et al.*, 2013). The last available productivity data point is for 2002. Since then the situation has probably deteriorated as farmers have had to cope with a 5.6% per annum increase in real fuel prices, as well as a 45% once-off increase in the statutory minimum wage for agriculture in 2013. Sheep farmers are rapidly exiting the industry (Reed and Kleynhans, 2009; Wessels and Willemse, 2013) and for survivors profit margins are slim (Conradie and Landman, 2013).

While the disappearance of the marginal sheep farm ought to increase productivity, it is unclear how the area's changing land use is affecting the performance of those who remain in business. The main concern is over predators; it is believed that lifestyle farms harbour predators which are forced to hunt lambs on neighbouring commercial farms since the natural prey of these predators is depleted everywhere. In addition, there is some concern over deteriorating carrying capacity on the surviving commercial farms, whether caused by overgrazing or climate change (Dean *et al.*, 1995). Where carrying capacity has already collapsed to a point of no return, no amount of good management will have any impact (Milton *et al.*, 1994), in which case one would anticipate farm-level productivity to vary substantially with grazing quality.

Although the necessary data on rangeland quality are not currently available to test this hypothesis fully, this analysis will at least investigate part of the question, by asking 1) How much does productivity vary on sheep farms? 2) What is farm-level productivity correlated with? and 3) What is the most efficient way of farming with sheep in the study area? The results will generalise to most parts of the Central Karoo and will contribute to a general understanding of how to maximise the productivity of all extensive sheep grazing systems. Data envelopment analysis (DEA) is ideally suited to the proposed analysis as it is not hampered by limited sample size in quite the same way as a stochastic frontier analysis is, and can decompose productivity into scale and pure technical efficiency effects. More importantly, the DEA algorithm identifies peers, or reference firms, for each member of the group which allows one to formulate tailor-made improvement strategies for all. It is recognised that there are many ways to farm with sheep (Milan *et al.*, 2003; Gaspar *et al.*, 2009). Here dominant peers will be used to investigate the best way to farm with sheep in the study area.

Data and Methods

The Laingsburg dataset

This study took advantage of a cross-sectional farm management dataset collected as background information for a study on predator behavioural ecology situated in Laingsburg district on the Central Karoo plateau of South Africa. Average precipitation is less than 120 millimetres per annum. The survey was conducted during a three week period in November 2012. It covered the 2012 production season and targeted all landholders in the district. Interviews were conducted as informal conversations in the local language, usually in the home of the respondent. Data were collected on land and livestock holdings, cost of production, the size of the previous season's lamb crop, landholders' attitudes to a set of potential threats to agriculture and the farmer's experience with predation. For several variables it was necessary to refer to farm records. Financial records were generally available, but most farmers had to rely on recall for reproductive data and predator losses. Since predation is a sensitive issue in the Karoo (Nattrass and Conradie, 2013), we were aware of the possibility of strategic bias and thus chose to collect reproductive data in the raw form in order to minimise such behaviour. For example, we asked for the number of ewes bred and lambs tail-docked instead of a lambing percentage figure. Furthermore, the replacement rate which should lie between 15% and 20% if ewes are rotated out of the flock after six years was used to check the validity of the reproductive figures provided; 80% of replacement rate observations fell within a plausible range, but the variable's 11% standard deviation is some cause for concern.

There was very good support for the survey from a number of community leaders, who helped to compile a convenience sample of 64 local landholders of whom 60 agreed to be interviewed (94%). The sample of 60 farms and the 38,060 small stock units on which data were collected, represent 80% of the farms and 79% of the sheep recorded for Laingsburg in the 2002 farm census (Statistics South Africa, 2006).

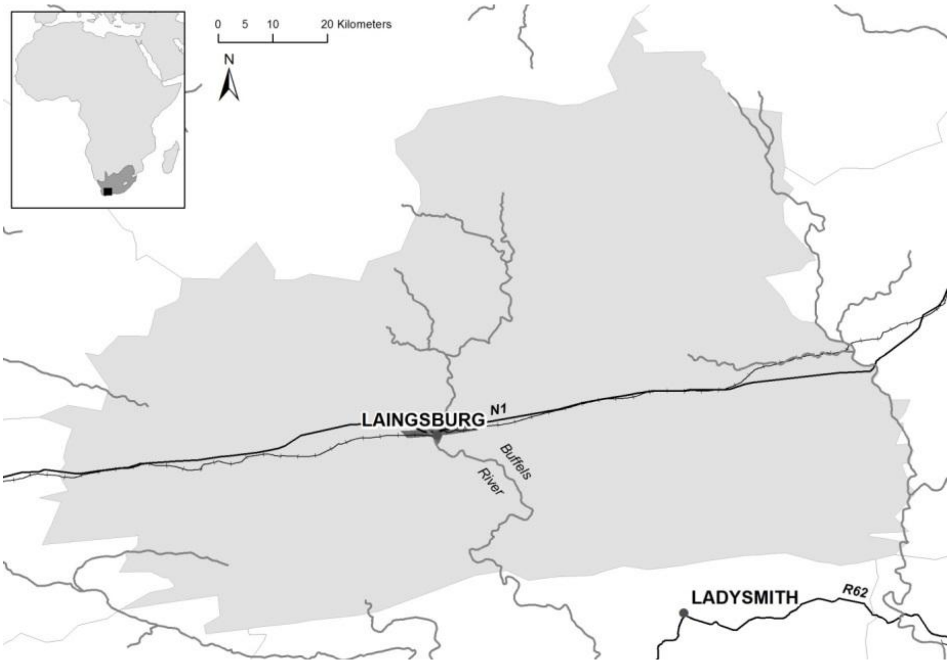

Figure 1: Location of the study area

Theoretical framework for DEA

DEA is a non-parametric programming approach to productivity benchmarking. The algorithm constructs a best-practice production frontier and expresses the performance of individual decision making units (farms) as a ratio of actual to best practice performance (Farrell, 1957). Input oriented efficiency is defined as:

$$F(y_i, x_i) = \min[\lambda_i : \lambda_i x_i \in L^+(y)]$$

where F is the production function which relates inputs (*x*) to outputs (*y*) for firm i. The efficiency level of the ith firm is found by solving the following linear programing problem:

$$\begin{aligned} T(y_i, x_i) &= \min \lambda \\ \textit{subject to} \quad zy &\geq y_i \\ zx &\leq \lambda_i x_i \\ z &\geq 0 \end{aligned}$$

where *z* is a firm specific vector of non-negative intensity parameters which are used to trace out convex combinations of inputs and outputs. The parameter λ allows for radial scaling of the original observations and their convex sets in order to find each observation's peers on the frontier. Fare *et al.* (1985)

decomposed this total efficiency into pure technical efficiency, TE (y_i, x_i), and scale efficiency, SE (y_i, x_i) as follows:

$$F(y_i, x_i) = T(y_i, x_i)S(y_i, x_i)$$

DEAP-1 (http://www.uq.edu.au/economics/cepa/) reports all three components. The difference between Coelli's (1996) constant and variable returns to scale frontiers is that in the latter the z's across the inputs must add up to one. Therefore, the input oriented variable returns to scale DEA model is:

$$\begin{aligned} T(y_i, x_i) &= \min \lambda \\ \text{subject to} \quad zy &\geq y_i \\ zx &\leq \lambda_i x_i \\ z &\geq 0 \\ \sum z_i &= 1 \end{aligned}$$

where $TE_i = \frac{y_i}{y_i^*} = \frac{1}{\lambda}$ and $SE_i = \frac{TE_i^{CRS}}{TE_i^{VRS}}$.

SE = 1 indicates constant returns to scale, SE < 1 indicates scale inefficiency (Banker *et al.*, 1984; Theodoridis *et al.*, 2012). If the sum of the associated λ's is greater than unity, the firm exhibits decreasing returns to scale and if it sums to less than unity, the firm exhibits increasing returns to scale (Banker and Thrall, 1992).

Specifying the production frontier

An extensive sheep grazing system is simple; one puts animals to pasture with a minimum of additional inputs to produce meat, wool, milk or a combination of all three. In the Karoo, sheep overwinter on pastures. The main infrastructure required is fenced paddocks and artificial watering points (Archer, 2000). The most common way to intensify production is to supplement natural grazing with purchased feedstuffs and this is often accompanied by a general increase in purchased inputs. Gaspar *et al.* (2009) used labour, extra feed, other purchased inputs (including land rental, fertilisers and veterinary costs, etc.) and total fixed costs (including land and breeding stock) to specify their frontier. Since theirs was a per-hectare model, herd size was not considered an input. Galanopoulos *et al.* (2011) modelled production at the farm-level, using the same variables as Gaspar *et al.* (2009) to do so, except that farm size entered to represent land and grazing days was included to account for the nutrition. Our model, in the spirit of that of Gaspar *et al.* (2009), expressed income per breeding ewe in the flock as a function of grazing land, family labour, hired labour and other purchased inputs. Of the four inputs, the variation in the amount of land allocated per ewe in the flock was the smallest (coefficient of variation = 0.39), while purchased inputs and expenditure on hired labour varied substantially (cv > 0.8). The variation in output per sheep (cv = 0.57) and the use of family labour (cv = 0.67) was intermediate. See Table 1.

Table 1: Variables used to specify the per-ewe production frontier (n=46)

Variable	**Unit**	**Mean ± SD**
Output	Rand	664 ± 394
Grazing land	Hectares	12.58 ± 4.88
Family labour	Fulltime equivalents	0.24 ± 0.16
Hired labour	Hours	61 ± 52
Other purchased inputs	Rand	259 ± 210

We found it relatively easy to collect input data but settled for a simulation of gross income per ewe in the flock based on the reported number of animals sold per flock and a reference sale price of R1,000 per slaughter lamb in order to get more farmers to participate. Where applicable, an estimate of wool revenue was based on the estimated mutton of the particular flock and its reported shares of wool and mutton in total farm income.

All farmers in the group keep sheep. Boer goats and angoras were reported by some farmers, but since goats in total represent less than 5% of total small stock holdings, they were safely ignored. For 65% of group, mutton represents the only source of income. For the other third wool on average contributes 39% of sheep income. Land per sheep included rented land. Family labour was not as carefully measured as we would have liked either; instead of hours worked per month or week, we only had a measure of fulltime work equivalents. A portion of each farmer’s time was assigned to his sheep enterprise according to the sheep enterprise’s share of household income. Where wives and adult children were indicated to be involved regularly in the sheep business, their labour was counted too. It is standard practice in the area for adult children and other family relations to pitch in with sheep handling when they visit the farm but, since no systematic data were available to quantify this contribution, it was not considered. Estimates of hired labour and other purchased inputs were taken from the income statement where financial statements were made available, and were otherwise collected from recall. Repairs and maintenance were included with other purchased inputs, but no data were available for capital investments.

Since DEA is a non-parametric technique, modelling is often iterative. Scores tend to rise with the number of inputs and outputs used to specify the frontier and if there are too few observations in the sample. Since none of the variation is attributed to statistical errors, outliers tend to influence results disproportionately. For these reasons it is recommended that one should have at least three observations for every input or output used and should discard any observations which lie beyond 2.5 standard deviations of the mean (Commonwealth of Australia, 1997). Of the 60 observations we started with, nine had to be dropped due to incomplete financial data, and a further five due to suspicious factor ratios. We have some confidence in the specification based on the remaining 46 observations as all four best practice farms identified in this version of the model are operated by individuals recognised in their community as good farmers.

Results and Discussion

Total, technical and scale efficiency

The group's mean score for overall efficiency was 0.674, while the mean scores for pure technical and scale efficiency were 0.812 and 0.804 respectively. The scores imply that the same output can be achieved with a third less inputs and that being right sized is as important for productivity as proper management. In the top third of the distribution almost everyone was technically and scale efficient. In the bottom third of the distribution, where the lowest overall score was 0.128, some farms were poorly managed at the right intensity, while others were properly managed but not intensive enough. Pure technical efficiency scores varied from 0.358 to 1.000 (fully efficient), and scale efficiency from 0.298 to 0.919 (almost right scaled) in the bottom third (see Table 2).

Since we estimated a per-sheep model, the scale efficiency scores reported here are a measure of intensity rather than an indication of the traditional concept of scale efficiency. Just 4% of production systems were found to be too intensive and a further 26% were found to be operating at the correct intensity. The remaining 70% of farms could theoretically be improved through intensification. This is a counter-intuitive result for the Karoo where most people believe that it is best to minimise costs. While employing more labour to tend sheep and spending more money on supplementary fodder or better genetics will almost certainly translate into greater sheep productivity, it is unclear if spending more on overheads, such as on fuel or repairs, would have any impact on productivity. Intensification in the land dimension, in other words allowing more land per sheep, should also improve productivity. Substitution possibilities are discussed below.

Correlates of productivity

Per-sheep productivity ought to vary with farm size and the size of the flock if there are economies of scale in sheep farming. The evidence is mixed; Galanopoulos *et al*. (2011) showed that farm size is a more important determinant of productivity than the price environment, while Gaspar *et al.* (2009) found efficiency not to vary across farm size categories. In this study overall productivity was uncorrelated with farm size, but positively correlated with flock size. The category mean flock sizes in Table 2 show that the real difference in flock size lies at the bottom end of the distribution, where we are convinced that lifestyle farming plays a role. A city professional who recently acquired land in the district described his purchase as: "*Eintlik net 'n duur braaiplek*" [Actually just an expensive barbecue pit] which corroborates Reed and Kleynhans' (2009) finding that the Karoo's lifestyle farmers are more interested in a farm's scenery and the quality of its accommodation than in its carrying capacity for sheep.

Given that farm size was not correlated with productivity and that flock size was, stock density ought to be correlated with productivity too, which it was. The negative sign on the correlation coefficient in Table 2 is there because the stocking density variable measures the number of hectares of grazing allowed per sheep rather than the number of sheep per hectare; a large number of hectares per sheep indicates a low stocking density and *vice versa*. The small difference in the category mean stocking density for the top and bottom third groups confirms that most farmers are aware of the region's fragile vegetation ecology and are not tempted to overstock. When asked explicitly about their grazing strategies, some people indicated that they try to farm at half the recommended stocking density, i.e. allow twice the recommended area per ewe in the flock, to protect the land's productivity. However, these stocking density norms are thirty years out of date and may be too generous for current climate conditions (Dean *et al*., 1995).

Table 2: Levels and correlates of overall efficiency for the Laingsburg sample (n=46)

Characteristic	Sample Average	Correlation with overall efficiency r	Top third	Of the sample middle third	Bottom third	ANOVA F-stat
Overall efficiency	0.674	-	0.991[a]	0.705[b]	0.346[c]	179.69***
Pure technical efficiency	0.813	0.848***	0.999[a]	0.864[b]	0.590[c]	32.46***
Scale efficiency	0.804	0.830***	0.991[a]	0.828[b]	0.605[c]	32.35***
Farm size (ha)	8,040	0.136				
Flock size (ewes)	681	0.249*	770[a]	714[a]	568[a]	1.03
Stocking density (ha/ewe)	12.6	-0.287**	11.6[a]	12.2[a]	13.9[a]	0.90
% woolled sheep	24	0.115				
% farm income from sheep	81	0.102				
% household income from farming	82	-0.122				
Lambs tail docked / 100 ewes in the flock	83	0.204†	90[a]	86[a]	74[a]	1.21
Animals lost to predators/ 100 ewes	9	-0.089				
Production cost (R/sheep)	320	-0.300**	280[a]	257[a]	418[a]	2.14†
Net farm income (R/sheep)	344	0.728***	607[a]	430[a]	16[b]	19.88***
Family history on the land (years)	78	0.355**	86[a]	74[a]	73[a]	0.29
Operator education (years)	13	0.023				
Operator management experience (years)	22	0.018				
Operator farming experience (years)	28	0.052				
Family labour (fulltime equivalents/ sheep)	0.24	-0.221†	0.20[a]	0.22[a]	0.29[a]	1.39

*** p≤0.01, ** p≤0.05, * p≤0.10, † p≤0.15, abc - Different letters in the same row indicate significant differences (p<0.05).

Given the objectives of lifestyle farming and the evidence provided by Elliot *et al.* (2011) that crop production crowds out certain shepherding functions on mixed sheep farms in Australia, one would expect the productivity of the sheep enterprise to be negatively correlated with share of household income from agriculture and positively correlated with the share of farm income derived from the sheep enterprise. Both correlation coefficients have the expected sign, but neither was significant. These results imply either that lifestyle farmers are equally as productive as fulltime operators, or that the type of lifestyle farmer described in Reed and Kleynhans (2009) is not included in the dataset because this type of landholder is invisible to a farm management survey.

Woolled sheep are sometimes thought to be more profitable than pure mutton sheep. The correlation coefficient between overall productivity and the percentage of woolled sheep in the flock was positive, but insignificant. Reproductive performance, measured as the number of lambs tail-docked and tagged at six weeks per hundred ewes in the flock, was marginally significantly correlated with overall productivity ($p \leq 0.15$). While losses to predators, expressed as a percentage of ewes in the flock, carried a negative sign, it was not significant. Productivity was strongly correlated with unit production costs and profitability. The top third farmers' average production cost per sheep was a third lower than the bottom third's average production cost per sheep, and their unit profits were forty times higher than that of the bottom third group. The bottom third barely broke even which implies that most landholders in this group either experienced a catastrophic drought in 2012, or rely on alternative means of support.

None of the proxies for operator quality were correlated with the productivity of the sheep enterprise. The exceptions were, curiously, cumulative family farming experience (rather than personal experience or formal schooling) and the amount of family labour used in the production process. The top third's families on average have been settled in the district for 14% longer than that the middle and bottom thirds' families. The amount of family labour employed per sheep is negatively correlated with productivity, with the top third producers on average using 50% less family labour per ewe in the flock than the bottom third. Total family labour employed per farm is uncorrelated with productivity.

Dominant technology variants

Laingsburg district is located on the southern margin of the Central Karoo plateau. It is surrounded by the *Swartberg* Wilderness in the south and the *Roggeveld* and *Nuweveld* Escarpment in the northwest. To the northeast the plains of the Central Karoo stretch for almost a thousand kilometres to the southern edge of the Kalahari Desert. The *Buffels* River, which bisects the district, marks the transition from predominantly winter to predominantly summer rainfall as well as the vegetation transition from the Succulent Karoo to the Nama Karoo biome. Nama Karoo has vegetation that is more palatable for livestock which this gives the area a better carrying capacity, despite its lower rainfall. Since Laingsburg district falls on the extreme edge of both rainfall distributions, rainfall is highly variable. Farmers have traditionally managed rainfall risk with a system of transhumance (*trekking*), in terms of which the four winter months are spent on the *trek* farm in the Succulent Karoo area and the other eight months of the year on the home farm in the Nama Karoo part of the district. Over the years many people have sold off their *winterveld,* often to lifestyle farmers. As a result few standalone *winterveld* farms remain in commercial production, and where they do, they always have a crop element of which the stovers provide an important element of summer grazing. On Nama Karoo farms it is now common to supplement poor winter grazing with purchased feed, the expenditure on which is negatively correlated with farm size (r = -0.2126†). In addition, a number of very large properties emerged on which the main response to rainfall risk is the sheer size of the property itself.

Radial contraction from an inefficient farm's actual input bundle to the best practice frontier identifies one or more benchmark firms for each member of the group based on shared factor ratios. In this study there were 21 frontier farms, of which only a few served as peers for anyone except themselves. A simple peer count was used to identify the most representative production systems, or dominant technology variants, from amongst the frontier farms. With peer counts of eighteen and twenty, Farms 12 and 3 emerged as the most representative production technologies in the district. These two farms also served as main peer, defined according to peer weights, for the largest number of observations (see Table 3).

Farm 3's production system is best described as extensive and is large by local standards. The owner of Farm 3 works on his farm full time but his wife is not involved in the business, which limits the amount of family labour available per sheep in the flock. Family labour is supplemented with a relatively large amount of hired labour, which in 2012 comprised 45% of out of pocket production costs. Farm 3's limited expenditure on other inputs is consistent with its scale efficiency score of 0.865. A quarter of the farm lies both against a steep mountain slope and on top of a mountain and can only be reached in a four wheel drive vehicle. Despite this tough terrain the farmer has found a way to use the land productively as his reported stocking density falls within the commercial range. Farm 3 operates a mixed flock and does not follow a system of transhumance. Yet it spends only R16 per ewe per annum on purchased feedstuffs, which means that farm size is the main response to rainfall risk in this case. Terrain ruggedness and the limited availability of family labour result in low reproductive performance and high predation losses. However, the production system is specialised in sheep insofar as sheep are the only farm enterprise and agriculture is virtually the only source of household income.

Table 3: Dominant variants of the sheep farming technology – efficient farms

	Extensive model		Intensive model	
Farm characteristics	**Benchmark Farm 3**	**Alternative Farm 7**	**Benchmark Farm 12**	**Alternative Farm 29**
Total peer count	20	7	18	4
Farms for which it serves as main peer	9*	3	3*	2
Scale efficiency score (intensity)	0.865	0.437	1.000	0.999
Revenue per ewe	492	198	720	738
Land ha/ewe	7.48	8.05	6.53	8.14
Family labour fulltime equivalent/ewe	0.05	0.06	0.19	0.08
Hired labour R/ewe	36	18	18	38
Other purchased inputs R/ewe	80	48	207	164
Total farm size(ha)	13,841	16,600	6,842	9,862
Flock size (breeding ewes)	1,850	1,690	1,047	1,200
Percentage woolled sheep	81	-	53	-
Percentage of farm income from sheep	100	100	70	100
Lambs born per 100 ewes	58	74	76	112
Sheep and lambs lost per 100 ewes	11	30	2	27
Sales rate – lambs sold per 100 ewes	33	20	56	74

* Joint main peer for four inefficient farms

Farm 12 is the polar opposite of Farm 3. Farm size is average for local conditions and comprises the traditional two sections of Succulent and Nama Karoo vegetation necessary for transhumance. It employs 280% more family labour and 159% more purchased inputs than Farm 3. The large endowment of family labour per sheep in the flock is made possible by the wife's fulltime involvement in the sheep business in addition to the husband's labour, and their smaller farm size. The farmer says of his wife "My wife is a better farmer than I am. She will be able to carry on by herself when I die". The wife's contribution displaces a significant amount of hired labour. Intensive shepherding results in a 30% better reproductive performance than reported by Farm 3 and virtually zero predation problems. The farm's stocking density is 13% higher than that of Farm 3, which is already above the sample median stocking rate. Their stocking rate is recognised by the owners as dangerously close to unsustainable. However, they have indicated that they will continue to stock at this rate in the medium term until they have put their two children through boarding school and college. In 2012 the farm derived 70% of its income from sheep and 30% from vegetable seed production, whilst the household received all its income from agriculture. However, Farm 12's business model is currently in flux; since the interview the owners have not renewed the contract on a rental property and sold off their *winterveld* because high predation rates made it unviable for them to continue with sheep farming on these farms. Apparently they are now in the market for land closer to their home farm. If they buy more Nama Karoo land, it will spell the end of transhumance for them and make them more specialised in sheep as the vegetable seed was produced on the winter farm, both of which will contribute to the operation's increased vulnerability to climate risk. However, the owners clearly feel that the benefits of lower predation risk more than outweighs the greater climate risk they will be facing.

Table 3 also contains data for two other less representative production systems which are worth discussing. At a scale efficiency score of just 0.437, Farm 7 is substantially more extensive than even Farm 3, whose scale efficiency score of 0.865 already indicates intensification to be desirable. Farm 7 is owned by a single man with some other sources of income besides farming, and who is described by his neighbours as having "few needs". Farm 7 produces sheep only and its flock consists of 55% Dorpers and 45% indigenous sheep. Indigenous sheep have an inferior quality, fattier, meat but make up for low meat prices with higher fertility and better resilience under extreme conditions. Consequently, compared to Farm 3, Farm 7 is able to substitute 20% more family labour and an 8% lower stocking density for almost 40% fewer purchased inputs. This system produces a 28% higher tagging rate than Farm 3 but is quite vulnerable to predation, which results in a sales rate that is 39% lower than the sales rate reported by Farm 3. Poor productivity is partly offset by farm size, which is 2.4 times larger than the median farm in the district. In addition, operating at a lower stocking density allows the owner of Farm 7 to avoid feeding sheep "as a matter of principle". Farm 7's business model is so hands off that when the farmer finds a sick sheep before it dies, he ships it off to his brother, who he describes as a "proper farmer". The brother's farm was found to be technically efficient and was run much closer to the optimal intensity (scale efficiency = 0.903), but it did not serve as reference for anyone perhaps on account of its extremely large size.

Farm 29, the alternative intensive model, is run by a semi-retired former extension officer, whose wife is not involved in the business and whose children are financially independent. The farmer maintains that he continues with the farm largely to keep himself busy and perhaps to save it for a grandson who has expressed an interest in farming. Although Farm 29 is 44% larger than Farm 12, its low stocking density, which is as low as that of Farm 7, is more of an indication of the owner's semi-retired status than of farm size. Farm 29 uses 21% less purchased inputs than Farm 12 and an amount of hired labour similar to that reported by Farm 3. In this case, hired labour does not substitute for family labour, as the farmer spends 60% more time per sheep in the flock than the owner of Farm 3. Farm 29 is not situated on particularly rugged terrain, but borders onto a wilderness area which might explain why it experiences ten times higher predation than Farm 12. However, good management and farming with caraculs more than make up for the property's unfortunate location as can be seen from its tagging rate of 112%.

The link between productivity and profitability

Despite the reference farms making equally efficient use of their inputs they are not all equally profitable, and despite the strong positive correlation between overall productivity and net farm income per sheep in the flock (r = 0.7282***), none of the four reference farms ranked amongst the five highest figures recorded for profit per sheep. One could argue that farmers maximise overall profits rather than unit profitability. Three of the four reference farms do indeed rank well in terms of overall profits; Farm 3, 29 and 12 placed third, fourth and fifth in the overall profitability ranking, in order of farm size. First and second place were taken by two of the largest farms in the district, which indicates that the profitability of a Karoo farm is influenced as much by size as by productivity. The message is simply that one should not be too small. However, the owners of smaller properties have no choice but to maximise per-hectare profitability in order to compensate for their limited size. Lessons can be learnt from Farm 12 and 29 about how to do this. Farm 12's recipe involves maximising both stocking density and purchased inputs to maximise the sales percentage, while Farm 29 is prepared to sacrifice some stocking density to save costs, and maximises the sales percentage in this way.

Farm 12 stocks 13% more densely than Farm 3 and achieves 31% higher profit per sheep by using twice as many purchased inputs, which results in a 73% higher sales rate and a 50% higher profit per hectare than reported by Farm 3. In this way Farm 12 is able to reduce a 50% difference in farm size to a 26% difference in overall profits. Farm 29 uses 74% more purchased inputs than Farm 3, but stocks 9% less densely than it. This strategy produces a 124% higher sales percentage and 31% higher profit per hectare than reported by Farm 3, which reduces the 29% difference in farm size to a mere 7% difference in overall profits. If one compares Farm 12 to Farm 29, it seems as if Farm 29 follows the smarter strategy. Farm 12 achieves 14% higher profits per hectare than Farm 29 by using 14% more purchased inputs and stocking 20% more densely. The price Farm 12 pays for the greater stocking density is a 23% lower sales rate, which precisely cancels out the potential gain of stocking more densely. It is possible that Farm 12 would have been better off stocking at the same rate as Farm 29. This question needs more attention as it is fundamental to successful farm management in any extensive grazing area anywhere in the world.

This leaves Farm 7, which ranked twelfth for net farm income per sheep and twentieth for overall profits in the group of 46. At R16.40 per hectare Farm 7's strategy yielded less than 20% of the income per hectare recorded by Farm 12. Farm 7's owner's philosophy to buy degraded land at the best possible price and then to rest it for ten years before putting sheep back on, indicates that he might be maximising long run rather than short run profitability. While this is no doubt good for sustainability, it is unlikely to be a viable strategy for most commercial operations, as they are simply too small to accommodate such yields. Restoration through resting might be more viable in the lifestyle sector where farmland does not have to pay for itself. However, if this is the case, then the recent rise of lifestyle farming could have important implications for regional output and food security, if not for productivity *per se*. Furthermore, just because the owner of Farm 7 believes resting to be a viable restoration strategy does not necessarily make it so. According to Milton *et al.* (1994) overgrazing first removes palatable species and then cover. Whether palatable species will return or not, depends on the availability of seed banks which will be affected by the duration and seasonal pattern of overgrazing. However, once cover is lost microclimates change to become hotter and drier which makes it more difficult for seedlings to recruit successfully. Bare patches become permanent and grow bigger over time. The only vegetation which might come back are weedy species that offer little grazing value. In this state, no amount of rest will make any difference. It is unclear how much of the district's land is this badly degraded and how the restoration process will be affected by the greater rainfall intervals which are already visible in the local rainfall record. This area also deserves further study.

Conclusion

This analysis investigated the relative productivity of extensive sheep farms in Laingsburg in the Central Karoo. We found overall efficiency to vary substantially, which indicates that there is room for improvement on certain farms. Scale and pure technical inefficiency were found to make similar contributions to productivity. The best practice intensive and extensive production models were clearly identifiable, which suggests that both technology variants are well understood locally, which in turn should make for a straightforward extension message. Having said this, almost half of the farms in the sample were technically efficient, which indicates that different farmers may have found different ways of coping with the financial pressure. It also suggests that over time new dominant technology variants might emerge.

Given the Karoo's aridity, the majority of scale inefficient farms were, unsurprisingly, found to exhibit increasing returns to scale. Increasing returns to scale means that production systems should be intensified, but it is important to realise that intensification implies a lower rather than a higher stocking density. The recommendation is to allow more land, and not less land, per sheep. Other avenues for intensification include spending more on purchased inputs (particularly on purchased fodder), and closer shepherding. With the recent increases in the cost of hired farm labour, we should expect a further shift to family labour, which already is at levels unprecedented in the rest of commercial agriculture in South Africa. Further jobs will be lost as a result.

The case of sacrificing short run profits to improve future prospects highlights the importance of taking a long term view on productivity management. Reproductive efficiency was surprising correlated only weakly with productivity and we could not establish predators to have a systematic impact on performance. Both of these conclusions go against common wisdom; if these results can be confirmed elsewhere or for other years it could dramatically affect how farmers organise their production systems. Our preliminary results suggest that maintaining grazing capacity may be much more important for sustainability than indiscriminate predator management or a blind pursuit of reproductive efficiency. However, until carrying capacity and predation pressures can be quantified for inclusion in the model, we cannot firmly establish how these factors impact on productivity. Improving the productivity estimate in these ways must be a priority, although doing so will be expensive, tedious, and time consuming.

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