The changing environment: Efficiency, vulnerability and changes in land use in the South African Karoo, 2012-2014

Abstract

Many parts of sub-Saharan Africa are becoming increasingly vulnerable due to high temperatures and low precipitation associated with climate change. The Karoo region in South Africa is particularly at risk and survey data from white commercial farmers are used to measure levels of efficiency for three years between 2012 and 2014 to illustrate the extent of this vulnerability. A stochastic production frontier is estimated and results show that average farm level efficiency fell by 3.2% per year over the period. The performance of the top ten farmers fell by 6.5% from an average efficiency of 92% to 86%. The bottom group fared much worse. Five of these withdrew from sheep farming altogether while the other five had an average decline of 24.5% decline in efficiency, falling from 49% to 37%. Adverse weather explains some of the decline and the continuing drought bodes ill for future farm performance. Increasingly marginal farming causes and is exacerbated by changes in land ownership. The causes of land ownership changes are mixed and include the uncertainty regarding the future of land reform in South Africa. The implications of farm efficiency for land reform policy are discussed.

Highlights

- Farms are increasingly vulnerable to climate change
- Farms operate at various levels of efficiency
- Less efficient farmers are being replaced by recreational land users
- Land reform is a major source of uncertainty
- Stress is contributing to farmers’ poor mental and physical health
- Land reform beneficiaries should avoid being further marginalised by receiving climate vulnerable and inefficient farms

Keywords: Climate change; farm efficiency; stochastic frontier models and time-varying error components model; changes in land use; rainfall; temperature

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1. Introduction

The established literature on climate change suggests that more extreme temperatures and increasingly variable precipitation will become commonplace, with Sub-Saharan Africa most at risk as average temperatures are already high and droughts are frequent. To compound the vulnerability of the region, there is a high dependence on agricultural production as a source of income, plus there are serious technology constraints (Kotir, 2011). It is expected that rising temperatures will affect farm incomes more than changes in precipitation (Kurukulasuriya et al., 2006) and in some places livestock will replace crops (Jones and Thorton, 2009), resulting in hunger and famine when pastoral systems fail (Pricope et al., 2013; Speranza et al., 2008). For existing livestock farmers this will have a direct impact on fecundity and the prevalence of disease, as well as on animal water requirements (Rojas-Downing et al., 2009; Thornton et al., 2009). It is already well established that arid rangelands are subject to a dynamic interplay between biotic and abiotic factors although which is dominant is unclear (Derry and Boone, 2010). However, what is certain is that these nuances are of little concern to the farmer, who simply needs to know the future carrying capacity of their land.

The effect of climate change on agriculture is also political and in South Africa land is highly contested, given almost 370 years of colonial dispossession. The 1913 and 1936 land acts have severely restricted access to farmland by black South Africans. By 1994, thirteen million black people were trapped into overcrowded homelands while just 60,000 white commercial farmers controlled 82.7 million hectares of farmland (Hall, 2004; Cousins, 2016). In the period to 2012 only 7.95 million hectares of farmland have been returned or redistributed by the government to black South Africans with a similar amount likely to be added through private acquisitions (Lyne, 2014). Frustrations with the lack of progress boiled over in 2018 resulting in renewed efforts to accelerate reforms (Aliber, 2019; Jara, 2019; Vink and Kirsten, 2019). In this context it is necessary to talk about the vulnerability of white farmers to adverse climate conditions as these are the only data available , and their experience remains the best predictor of the likely experience of future black beneficiaries.

In the Karoo region in South Africa, agricultural production is already economically marginal (Conradie and Landman, 2015) and the farming system has experienced little technical progress over the last century (Conradie et al, 2009; Conradie et al 2013). However, despite the numerous challenges, some farmers are more efficient than others (Conradie and Piesse, 2015), which could mean that those are more likely to be resilient to climate change

(Azzam and Sekkat, 2005). Therefore it is useful to measure current levels of farm efficiency and investigate whether any relationship between efficiency, drought and changes in land use can be identified. This is predominately a technical investigation from which policy recommendations stem.

The paper makes three contributions to the literature. The first identifies changes in efficiency levels of white commercial sheep farmers in the Karoo, an environment of increasing vulnerability due to climate change. The second links efficiency to meteorological data, which is important as the Karoo is just one arid region amongst many in Sub-Saharan Africa and these results are an indication of the future in a much broader context. A particularly important issue is whether the gap between best and worst performers is increasing or decreasing. The third contribution seeks to understand the impact on this specific group of farmers of changes in land use. This can be due to the increasing move towards more recreational land owners and a decline in the system of farm stewardship that has passed from one generation to another for decades, with the social implications that follow, and uncertainty around land reform legislation.

The paper is structured as follows. The next section reviews the scant literature that has incorporated climate change data into econometric modelling. This is followed by a detailed description of the appropriate form of the stochastic frontier model used here. This is important as the efficiency estimates analysed further in section 5 depend on the choice of functional form. Standard likelihood ratio tests determine the most appropriate functional form for these data. This section also outlines the data and rationale for the choice of variables used. The results of the empirical estimation are in Section 4. To enrich the paper further a discussion follows that draws on detailed qualitative knowledge of this farming community. This provides some justification for the results of the quantitative analysis and goes some way towards explaining the effects of climate and change of land use on the participants of the study. The final section concludes and offers some policy proposals.

2. Climate Change and Farm Efficiency

The empirical literature addresses climate change in one of two ways. The first, which is favoured by climate scientists and geographers, is the Ricardian approach in which net farm income is specified as a function of temperature, precipitation and other relevant abiotic and socio-economic factors (for example, Kurukulasuriya et al. (2006) discussed above). The second is used by economists and includes weather variables in a standard production function where some elements are random. For the past forty years the theory of production has recognised that performance varies with resource quality and management skills. Early work by Aigner and Chu (1968) considered a linear production function where the non-negative error term was associated with technical inefficiency that represented management and other factors. Aigner et al. (1977) and Meeusen and van der Broeck (1977) independently proposed the stochastic frontier production function model, that added a symmetric random term to account for statistical noise, and more recently Kumbhakar (1990) extended the cross-section model for panel data and proposed the inclusion of technical progress and a time varying inefficiency effect. In these models, the ideal outcome is technical progress with convergence, that is, a positive coefficient on the time trend with falling inefficiencies over time as best practice transfers from leaders to followers. These econometric approaches are used in this paper.

In principle it should be simple to adapt the productivity model to include climate change (Rosegrant and Evenson, 1992), but due to the complex interplay among weather variables this has not always proved to be straightforward. For example, Baten et al. (2010) found that temperature was statistically significant and with the expected sign but this was not the case for precipitation. However, Solis and Letson (2013) found the opposite, with rainfall significant but not temperature although heat stress lowered farm output. Salim and Islam (2010) studied the ability of research and development expenditure to offset the negative effects of rising temperatures and found that although there was a strong correlation between productivity growth and rainfall, it was not possible to show the direction of causality in their time series model.

In this paper, the effects of temperature and precipitation on farm productivity are modelled in relation to the Kumbhakar efficiency error term. The objective is to discover whether farm efficiency is correlated with rainfall and heat stress and to observed changes in land use and thus to explore the causes of vulnerability in the Karoo.

3. Model Specification and Data

Modelling technical efficiency using panel data is commonplace and the form of the production function is largely similar in the literature. An interesting paper by Kumbakar et al. (2014) compares several specifications and allows for different assumptions related to heterogeneity and heteroscedasticity. They introduce a model that differentiates between time-invariant and time-varying inefficiency effects. The authors suggest that in most cases there are high levels of sensitivity between the models and that care should be taken in interpreting the results. For this reason, the qualitative data introduced in section 5 is especially pertinent and the specification tests in section 4 essential.

3.1 The time varying error components model

The model estimated is a translog stochastic production frontier with Hicks neutral technical change and time varying inefficiency effects for a panel of N firms over T time periods, similar to Hadley (2006).

$$\ln Y_{it} = \alpha_0 + \sum_{k=1}^{K} \alpha_k \ln x_{kit} + \sum_{k=1}^{K}\sum_{j=1}^{J} \alpha_{jk} \ln x_{kit} \ln x_{jit} + \alpha_t t + v_{it} - u_{it} \quad (1)$$

where

$$\mu_{it} = \eta_{it}\mu_i = e^{-\eta(t-T)}\mu_i; t \in \tau(i); i = 1,2,\ldots,N \quad (2)$$

In this specification, Y_{it} is the output of farm i in period t and x_{kit} is the amount of input k used by farm i in period t. These inputs are stock sheep and goats, direct expenditure on sheep, labour and machinery. The vector of α's are parameters to be estimated. The error term v_{it} is assumed to be independently and identically distributed N$(0, \sigma_v^2)$. The variance of the inefficiency term (μ_{it}) is measured by γ = $\sigma_\mu^2/(\sigma_\mu^2 + \sigma_v^2)$ (Battese and Corra, 1977). If γ = 0 a mean response function is a sufficient representation of the data, that is, no inefficiency exists for any of the farms in the sample. If γ ≠ 0, the time varying inefficiency term, μ_{it}, can follow a truncated normal N(μ, σ_μ^2) or half-normal distribution N$(0, \sigma_\mu^2)$ depending on the estimated value of the parameter μ (Battese and Coelli, 1992). If η =0 there is no trend in the distribution of inefficiency scores over time. If η > 0 there is convergence in scores and if η < 0 scores diverge. The low farm densities typical of arid zones sometimes dictate the use of non-parametric analysis (e.g. Gaspar et al., 2009 or Theodoridis et al., 2012) or a simple Cobb Douglas specification (Toro-Mujica et al., 2011; Perez et al., 2007). With a total of 199 observations over the three waves (Table 1) it is possible that the more flexible translog production function would be too ambitious so this was examined. A translog production function includes squared terms and all the cross products of the basic inputs, which allow output elasticities and elasticities of substitution to vary with levels of input. Since the Cobb

Douglas is nested within the translog, a likelihood ratio test can determine the best functional form.

The second specification test compares the log likelihood statistic for the mean response specification of the preferred functional form to the stochastic frontier model. The third test, $\eta = 0$, examines whether inefficiencies increase, decrease or remain constant over time. The final test investigates the possibility that the frontier itself is shifting over time. Evidence of Hicks neutral technical progress is provided by $\alpha_t > 0$.

3.2 Data

The data are from the Karoo Farm Management Survey, which covers 1.6 million hectares of farmland on the southern fringe of the Karoo. Input and output data describing the farm were the primary focal questions of this survey study. Conducted annually between November 2012 and September 2016 the study used in-depth interviews with its participants. During this time the region was visited often for formal and informal engagements that provided many opportunities for participant observation. For more detailed descriptions of the project see Conradie and Landman 2015, Nattrass and Conradie 2015, Nattrass et al. 2015 and Conradie and Nattrass, 2017. The study area supports 161,000 stock sheep and goats (Stats SA, 2011) on 193 farms (Stats SA, 2006). Most farms consist of multiple cadastres, including rented land. The study area is 61% of the combined agricultural districts of Beaufort West, Laingsburg and Price Albert. A snowball sample of 102 farmers (53% of farmers in the study area) was approached of whom 75 gave usable responses. These respondents formed Wave 1 of the study (2012). In Wave 2 (2013), there was a 2% attrition rate and in Wave 3 (2014) a further 12.7% attrition rate, meaning that 58 of the original 75 farmers were surveyed in all three waves. The low initial response was due to the demands of the questionnaire relative to the sophistication of farm records and the sharp increase in attrition in wave 3 was because of difficult growing conditions (section 5.1). The unbalanced panel contains 200 observations from 75 farms over three years. One observation with zero output was omitted.

The data can be considered representative of white commercial livestock production in the area but the survey does not capture all agriculture or land use. Limited groundwater sources support some crop production on a small scale that was excluded from the efficiency analysis. In the case of mixed farms, that is, those including crops, overhead costs were allocated according to the share of sheep in the gross output of the total enterprise. The very small number of goats (4%) was included with the sheep. The survey uncovered several (sheep) farms that no longer had sheep or that had far too few sheep for their size. These farms have been bought up by outsider businessmen[1] since the early 2000s as holiday or *lifestyle* farms (Reed and Kleynhans, 2009). The plan was to include *lifestyle* sheep farms in the analysis to compare their efficiency with that of commercial operations, but they are underrepresented in the sample because their owners were unavailable for interviews or resistant to alternative modes of data collection and their managers were not able to supply the financial data needed for the efficiency analysis.

Although the Karoo pastoral production system is very simple, land and land-enhancing and labour and labour-enhancing inputs are necessary in the production function. Since sheep and goats convert primary plant production into mutton and fibre with little additional input, farm size and stock numbers are highly correlated ($\rho = 0.7815$, $p \leq 0.000$). To avoid collinearity between the land and livestock inputs (see footnote 1), only the stock variable was included in the production function.[2] The typical land-enhancing inputs are feed, animal nutrients and medicines and investment in the genetic quality of flocks. These expenditures were combined into a single variable: sheep cost. Labour is represented by the wages paid to hired workers only, with family labour excluded. Fuel and repairs and maintenance of vehicles and machinery were combined to create the labour-enhancing input: machinery. Other capital expenditures are excluded as they are land- rather than labour-enhancing and depreciation was not considered because vehicle and equipment values were unavailable. Output included mutton and fibre income. Costs and revenues are expressed in constant 2015 prices using the relevant price indices from the Abstract of Agricultural Statistics (Department of Agriculture, Forestry and Fisheries, 2016).

Insert Table 1 here

Table 1 summarises the input and output data from the survey that was used in the production function. None of the annual increases in the table were significant at a probability of $p \leq 0.05$, which indicates a degree of stagnation similar to that reported in Conradie et al. (2009). The coefficient of variation (cv) indicated that sheep costs vary most (cv = 1.23) and the mechanisation input least (cv = 0.83). Land productivity, income per unit of land, (cv = 0.56) varies less than any of the inputs while labour productivity, income per Rand of wages paid, (cv = 1.16) is uneven. The Kruskal-Wallis equality of populations rank

[1] Also predominately white although not exclusively.

[2] Whilst the authors acknowledge that land is usually included in an agricultural production function, much of Karoo land is marginal and with minimal access to water and therefore livestock is used as a proxy for land.

test shows a decrease in labour productivity in wave 2 when the statutory minimum wage for agriculture rose by 51% and this is significant ($p \leq 0.0573$). The natural logarithms of inputs and outputs were used to specify the Cobb Douglas model and the logged variables were mean centred in the translog production function estimation to ease interpretation of the results.

4. Efficiency Analysis

The first contribution to the literature is efficiency analysis and Tables 2 and 3 present the main empirical results thereof. In Table 2, the maximum likelihood statistics for the Cobb Douglas and translog frontier production functions (without time trend) are the first test. The χ^2 statistic exceeds the critical value of 18.307 for ten degrees of freedom[3]. Rejecting the null hypothesis indicates that the Cobb Douglas functional form is not an adequate representation of the data. In test 2 the log likelihood value of the translog frontier is compared to the log likelihood value of its mean response function and since the test statistic exceeds the critical value of 8.542 for three degrees of freedom we proceed with a translog frontier production function. In test 3 this model is estimated with and without η. Since the test statistic of 9.272 is greater than the critical value for one degree of freedom of 3.840, this parameter is retained. In the final test a time trend is inserted into the translog frontier to capture possible technical progress but this time the test statistic of 1.770 was less than the critical value for one degree of freedom, resulting in the stochastic production frontier model presented in Table 3.

Insert Table 2 about here

Insert Table 3 about here

Table 3 reports the maximum likelihood estimates of the preferred model plus the values of the parameters σ^2, γ, μ and η, all of which are significant at 99% confidence level. Sheep are a non-linear input that interacts with labour and machinery but is used in fixed proportions with sheep-specific expenses such as feed, medicines and ram purchases. In addition, output and machinery are non-linear and labour and machinery are substitutes, as expected. There is some evidence that labour is non-linear in output and that there is a degree of substitution between labour use and sheep costs. Sheep cost is non-linear in output too.

[3] $LR = -2[LLH_{restricted} - LLH_{unrestricted}]$ is distributed chi-squared with degrees of freedom equal to the number of restrictions imposed. When the null hypothesis is the restriction that $\gamma = 0$, the likelihood ratio (LR) statistic follows a mixed chi-squared distribution described by Kodde and Palm (1986

Summing the coefficients gives a crude measure of returns to scale which are slightly increasing in the translog model (1.105) . This model assumes constant technology but the significance of η provided evidence of divergence (see Figure 1).

Amad and Bravo-Ureta (1996) interacted time with individual inputs in the production function module to identify the source of growth, or in the case here the source of decline, but it made no sense to implement this strategy unless the time trend is significant, which it was not. Insert Figure 1 here

Figure 1 reports the distribution of efficiency scores where each colour represents an individual farm. It clearly demonstrates the decline in the performance of many of the farms in the sample and a tendency for the weaker performers to drop out of wave 3. On average, scores fell by 3.2% per year. In period 1, 2012, farm productivity varied between 3% and 94%, with a mean of 73% and a standard deviation of 17% (cv = 0.23). Ten farms achieved more than 90% efficiency while four farms were below 40%. In 2013, seven farms remained above 90% and five fell below 40%. Mean scores fell to 69% and the range was similar to period 1. The performance of the group declined further in period 3 to a mean of 67% and a maximum of 92%. The minimum performance improved to 22% because the three worst performers from the previous two years refused to be re-interviewed and thus were excluded from year 3. The coefficient of variation increased to 0.27 in period 2 and went back down to 0.26 in period 3.

5. Discussion and Interpretation

5.1 Micro-knowledge of the Karoo farming community

Eight out of ten of the worst performers wholly or partly dropped out of sheep farming when growing conditions became difficult. In three cases this was possible because they each had a lucrative vegetable seed enterprise and all three farmers plan to reintroduce sheep when conditions improve. The fourth also only stopped temporarily as the farmer had achieved a scant income from sheep during 2012 or 2013 due to drought and predators and he is able to subsist on savings. The worst group also contained four lifestyle farmers that subsidize fodder for core flocks with off-farm income. Three of the four lifestyle farmers do not live locally and are likely to leave permanently if conditions get worse. Only one is likely to return to sheep farming when conditions improve. The 9th member of the bottom group recorded a sharp decrease in productivity following a family tragedy and operations were scaled down but never quite stopped and the 10th whose business also continued through the drought practices extremely low intensity production that relies on economies of scale.

On the other hand the top score was consistently above 90%. This individual is 55 years old and has been farming his whole life, until recently in partnership with his father. He is married with children who are expected to take over the farm eventually. He operates on 36,000 hectares with over 3,000 stock sheep, which makes this farm one of the largest in the area. Historically, the flock has consisted of 50% *Dorper* sheep and 50% woolled sheep but this farmer is now in the process of switching over to *Meatmaster* sheep, a cross breed that is believed to be more fertile and hardier and have a flocking instinct that protects against predators, which is a major problem in the area (Nattrass and Conradie, 2018). The farm is spread across five properties which gives grazing flexibility. One substantial unit is rented. This farmer is considering buying more land, preferably the portion currently rented, to combat the weakening terms of trade across the industry (Nattrass and Conradie, 2015) although he fears that he might be operating at the limit of viable scale already. Climate change is less of a concern for him than security of tenure and he has definite ideas about which part of the district is the best farmland. He has considerable farming experience, which is just one of the many reasons for his success (Conradie, in press) but he also has some of the best land in the district and enough of it for it to remain in reasonably good condition.

In wave 1 nine other farmers were more than 90% efficient and eight out of the top ten maintained this performance in wave 2, while just two were still above 90% efficiency in wave 3. However, the top ten were all still above 85% efficiency in period 3, which demonstrates that this group is relatively less vulnerable to the general collapse in the region, whatever the cause. Good performance is not a function of farm size in this group; three of the top ten are medium sized and four are small scale operations. Nine out of ten describe themselves as full time sheep farmers, including a teacher who retired to farming and another individual who holds a part time job overseeing a neighbouring *lifestyle* farm. The one *lifestyle* farmer in the top group is in this position because in preparation for selling the farm to another *lifestyle* farmer he sold off sheep in order to terminate his flock.

5.2 Efficiency and weather: rainfall and temperature

It is clear that a relationship exists between drought, heat stress and farm productivity and Table 4 uses data from four reference sites in the Central Karoo to show the farm-level Kumbhakar efficiency scores vary with these climate variables. Rainfall is relative to the long term median precipitation, which is lowest at Laingsburg village (112 ± 51 mm) and highest at Beaufort West village (218 ± 81 mm). The other two sites are intermediate in terms of rainfall, although hotter than either rainfall extreme. Tests on the pooled data show that the least productive farms are located around Laingsburg and Prince Albert, while Koup and Beaufort West are more productive sites, but the differences are not significant for the individual years.

Insert Table 4 here

To test the impact of these admittedly crude climate change variables on efficiency an OLS regression was estimated with the results in Table 5. Following Benjamin et al (2018), we report results as statistically significant only if the p-value is less than or equal to the 0.005 level and as statistically suggestive if the p-value is less than or equal to 0.05. Efficiency has a positive and statistically significant relationship with rainfall percentage. The relationship with heat stress (defined as days over 40 centigrade) has a small effect and is not statistically significant. However, the interaction between rainfall percentage and heat stress is statistically suggestive and negative. The marginal effects indicate that the dominant variable in the interaction is rainfall which is still significant although smaller than in the underlying model. In the arid climate of the Karoo it was expected *a priori* that rainfall would have more of an effect than heat stress, which in this area is more extreme than the usual days over 30°C.

Insert Table 5 here

5.3 Efficiency and land use change

There is detailed but quite sensitive information on land use change over the period 2012 to 2017. This was anonymised and shown in Figure 2, which overlays the GIS land use layer by 9-minute hexagons coloured to match the dominant land use in each cell. It is important to note that the data refer to land use, not land ownership.

Land use is classified as one of four types: 1) *Bona fide* farming if it represents a household's main source of income, 2) *Semi-subsistence* if it is a household's only livelihood but not enough to allow them to maintain a reasonable standard of living: 3) *Lifestyle* if it contributes only a minor part of household income: and 4) *Transitional* if the farmer is seriously ill or has recently died and hence there is uncertainty about whether the land may convert to another land use type on the near future. As explained above, *lifestyle* farmers are different from those owning game farms as they maintain a remnant of sheep far below the commercial stocking rate and ownership is still predominately, although not exclusively, white. The classification reflects the local understanding of land use differences, but since being classified as type 2 or 4 amounts to failure, it was considered unethical to identify the precise location of these farms. The main change observed over this period was the sharp increase in ill-health and death of farmers, probably as a result of the steadily worsening growing conditions and other pressures. Over the decade 2008-2017 the worse affected part of the study area experienced six very dry years (average of <60% of expected rainfall) and just one exceptionally good year (149% of expected rainfall). While it is possible to survive one or two bad years, several consecutive drought years can cause financial stress that will eventually result forced sales as debt exceeds the collateral value of the land.

Insert Figure 2 here

Karoo farms are family run with established traditions of multigenerational management. Hence, farms become more vulnerable when their owners fall ill or die for a number of reasons. Productivity is impaired if the farmer becomes too ill to oversee day to day farming activities or if control is handed over to an inexperienced family member or to hired workers. Karoo farming is not just historically racialised (O'Laughlin *et al.*, 2013), but also gendered (Palmer, 2011), leaving many widows with insufficient training and experience when their husbands fall away while their sons will have been raised to take over. Heirs can sell the land or return to farm it fulltime, but this seldom happens as farm incomes are usually not match for off-farm salaries, in which case the farm changes from *bona fide* to *lifestyle*.

Another important element of land use change is caused by outsiders buying into the area for recreation, investment or niche farming purposes (Wessels and Willemse, 2013). Reed and Kleynhans (2009) reported that *lifestyle* farmers were responsible for half the land purchases in the Central Karoo between January 2005 and October 2007. These properties are closely clustered, such as in the rain-shadow of the *Swartberg* Mountains, where conditions are the most marginal. Figure 2 illustrates the spread of *lifestyle* clusters, which in part implies sales by vulnerable *bona fide* sheep farmers who are forced into distressed sales of their spare farmland. This is problematic because it reduces their future ability to respond to microclimate variability.

The practice of retaining additional farmland developed as farmers hedged their risk of rainfall variability. This is particularly the case for the study area as it straddles the summer-winter rainfall divide. Farms in the summer rainfall region were twinned with smaller winter rainfall properties so that livestock can be moved for three or four months of the year to exploit the additional resource and escape the worst of the drought. Unfortunately, there is a high demand amongst *lifestyle* farmers for these farms in the winter rainfall area because the properties are smaller, more affordable and have better road access. Thus, while the main farm may appear to carry on successfully after the sale of the additional farm, the loss of this option to insure against climate variability could increase the probably of crisis, and further accelerate land use change (Derry and Boone, 2010).

Land use change from *bona fide* to *lifestyle* farming is not necessarily bad for productivity. If the new owner has the desire and means to invest in sheep farming, productivity could rise provided that suitable management is in place. There are several examples of new arrivals that have consolidated small semi-subsistence properties into large scale sheep operations with high productivity potential. *Lifestyle* farmers that follow this approach are generally accepted by the *bona fide* farming community and are readily absorbed into it. These outsiders are valued for their business expertise and contacts in the wider world and are favoured by locals because they create jobs and spend money in the area. In exchange, local people will share expertise on sheep farming. While the benefit to community networks of this form of land use is obvious, the productivity effects must be monitored, which makes it important to include these farms in future farm surveys. However, not all *lifestyle* farmers are committed to farming and some neglect fence maintenance and predator control as they value rewilding as evidence of the recovery of their land. While complete rest for twenty years could restore carrying capacity (Seymour et al., 2010), survey evidence of these benefits is still lacking in the Central Karoo.

5.4 Implications of Efficiency for Land Reform

Finally, the issue of land reform inevitably affects efficiency for current holders. The ANC government set a 30% land reform target in 1996 but this was never properly funded and practical details were hazy (Lyne, 2014; Aliber, 2019). Lack of progress in implementation resulted in political risk and this was exacerbated in 2016 when the ANC's election conference tabled a motion to adopt land expropriation without compensation. Land reform without compensation can be financially devastating for farmers who have their total wealth tied up in the farm. Uncertainty about which farms will be targeted is a major cause of stress for farmers. Many *bona fide* farmers want to leave the sector and are trying to sell to *lifestyle* farmers, but these sales are drying up too as *lifestyle* farmers begin to realise that they too are might be at risk of expropriation without compensation, hence making the purchase of land potentially extraordinarily risky. It will be advantageous from a productivity perspective if *lifestyle* farms were included or even targeted in the reforms for and future land reform beneficiaries (Conradie, 2019). Either way it is important to reduce uncertainties as soon as possible as it provides incentives to farmers not to invest in farm upkeep and to overgraze, which could do irreversible harm to productivity and make the farm unviable for a land reform beneficiary.

These efficiency estimates are equally important for future land holders as it warns of the risks that climate change (drought and heat stress) poses to the technical efficacy performance of the farming system. These concerns are especially important if, as Du Toit and O'Connor (2014) argue, we are again at the onset of the next multi-decade drought in the Karoo. The traditional remedies to mitigate climate risk, such as having large farms comprising of multiple parcels, nonetheless remain relevant although this remedy is arguably politically difficult to justify especially in the face of demands for widespread redress (Bernstein, 2013; Walker, 2015).

6. Conclusions

Lower precipitation and higher temperatures resulting from climate change increase the risk to agricultural production, especially in Sub-Saharan Africa. This paper uses survey data from the Central Karoo district of the Karoo region in South Africa to assess the impact of reduced rainfall and higher temperatures on the efficiency of local sheep farmers. A stochastic frontier production model was used to measure efficiency over a three-year period from 2012 – 2014. The results show that efficiency levels fell over the whole sample in this period but the farms at the bottom of the distribution fared much worse by the end of the period than those at the top. This implies a degree of vulnerability to potentially worsening future rainfall conditions, which while still mild, has already had a substantial impact on transforming local land use patterns. In the past variations in rainfall could be managed by moving livestock from one part of the district to another but the sale of these additional grazing sites has restricted many farmers' ability to respond to unpredictable rainfall. Regional productivity is further undermined by the sales being made to *lifestyle* farmers who, because they have other sources of income, have lower incentives to farm efficiently.

Two main policy points emerge from this analysis. The first policy point is regarding the detail (benefits and recipients) of drought relief which needs to be more carefully investigated as there are many other demands on the South African fiscus.

The second is regarding land reform. Maintaining the balance between reaching as many beneficiaries as possible and protecting the productive capacity of the sector is a quandary chiefly for politicians. The inconvenient reality that emerges from this study is that Karoo land is generally unproductive, which undermines the viability of small farms especially during droughts. The more uncertain the redistribution process, and the longer it takes, the greater the risk that short-sighted decisions by current white landowners will do permanent damage to the farm viability. Historically, the alternative source of grazing was a spare farm, but if main and spare farms go to different beneficiaries both could be worse off than if the combined farm was intact. Redistribution should be a process that avoids further marginalisation. Yet redistributing land that is at risk of (or already) becoming less productive (because of climate change) can set up beneficiaries to fail despite no fault of their own. It would be equally disempowering for a land beneficiary to become a dependant on constant drought relief. The Karoo is a changing environment and policy must reflect these changes.

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Table 1: Inputs and Outputs (thousands of South African Rand in constant 2015 values, 2012-2014, plus land and labour productivity

Variable	**2012 (n = 72)**		**2013 (n = 70)**		**2014 (n = 57)**	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**
Income from mutton and fibre	576	604	592	600	701	807
Stock sheep and goats (number)	848	872	872	862	1009	1061
Sheep costs: feed, remedies, rams	69	81	62	81	80	96
Total wages paid to hired labour	55	49	67	57	72	68
Transport, fuel, repairs, maintenance	79	70	84	65	90	74
Land productivity (Income /ha)	62	32.8	63.5	35.9	63.8	37.3
Labour productivity (Income/Wages)	15	21.1	10.6	8.3	10.6	7.0

Table 2: Hypothesis tests for the specification of the stochastic frontier model

Hypothesis	Description	Log likelihood of restricted model	Log likelihood of unrestricted model	χ^2 statistic[4]	Degrees of freedom	$\chi^2_{0.95}$
$\alpha_{jk} = 0$	Is Cobb Douglas sufficient?	-143.990	-116.994	53.991	10	18.307
$\gamma = \mu = \eta = 0$	Is the translog form a mean response function?	-145.940	-116.994	57.892	3	8.542
$\eta = 0$	Are the inefficiency scores constant over time?	-121.63	-116.994	9.272	1	3.84
$\alpha_t = 0$	Is the frontier itself constant?	-116.994	-116.109	1.770	1	3.84

[4] Mixed χ^2 distribution described by Kodde and Palm (1986) and Dinar et al. (2007)

Table 3: Maximum likelihood estimates of the translog stochastic production frontier (n = 199) – Dep var = ln(Income)

Variable name	MLE	Std Error
Constant	0.262***	0.060
Stock	0.743***	0.080
Cost	0.098***	0.035
Labour	0.209	0.060
Machinery	0.055	0.068
$Stock^2$	0.190**	0.079
Stock x Costs	0.079	0.059
Stock x Labour	0.191***	0.051
Stock x Machinery	-0.474***	0.144
$Costs^2$	0.010	0.006
Costs x Labour	-0.086**	0.034
Costs x Machinery	-0.010	0.056
$Labour^2$	0.014**	0.007
Labour x Machinery	-0.078***	0.026
$Machinery^2$	0.315***	0.058
σ^2	2.800***	0.668
γ	0.963***	0.010
μ	-3.284***	0.642
η	-0.178***	0.54
Log likelihood statistic	-116.994	

*** p≤ 0.01, ** p≤ 0.05, * p≤ 0.10 on the two-tailed *t*-test

671 **Figure 1: Predicted decrease in farm-level efficiency in the Karoo, 2012 - 2014**

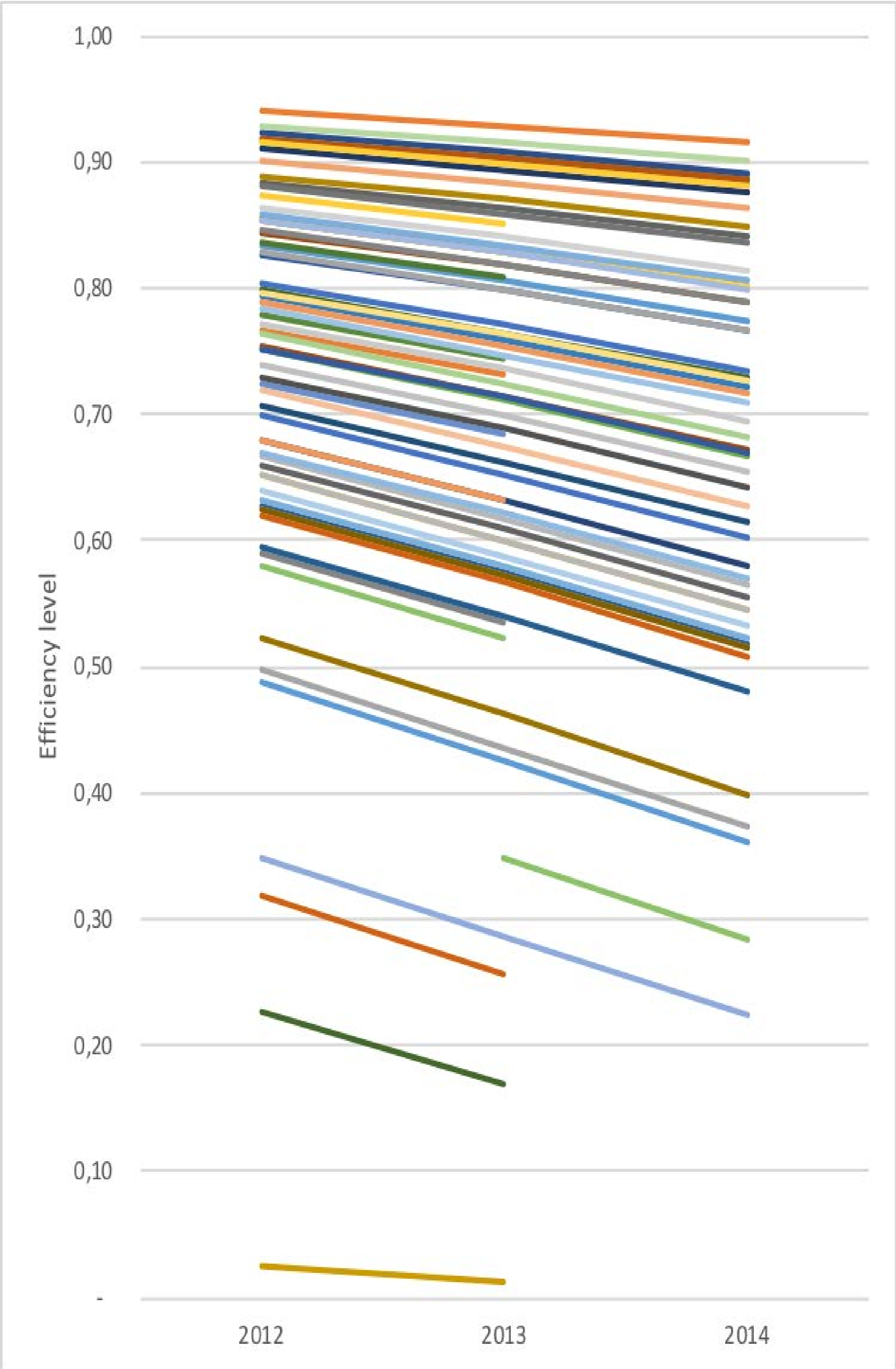

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Table 4: Rainfall, heat stress and farm efficiency at four sites in the Central Karoo

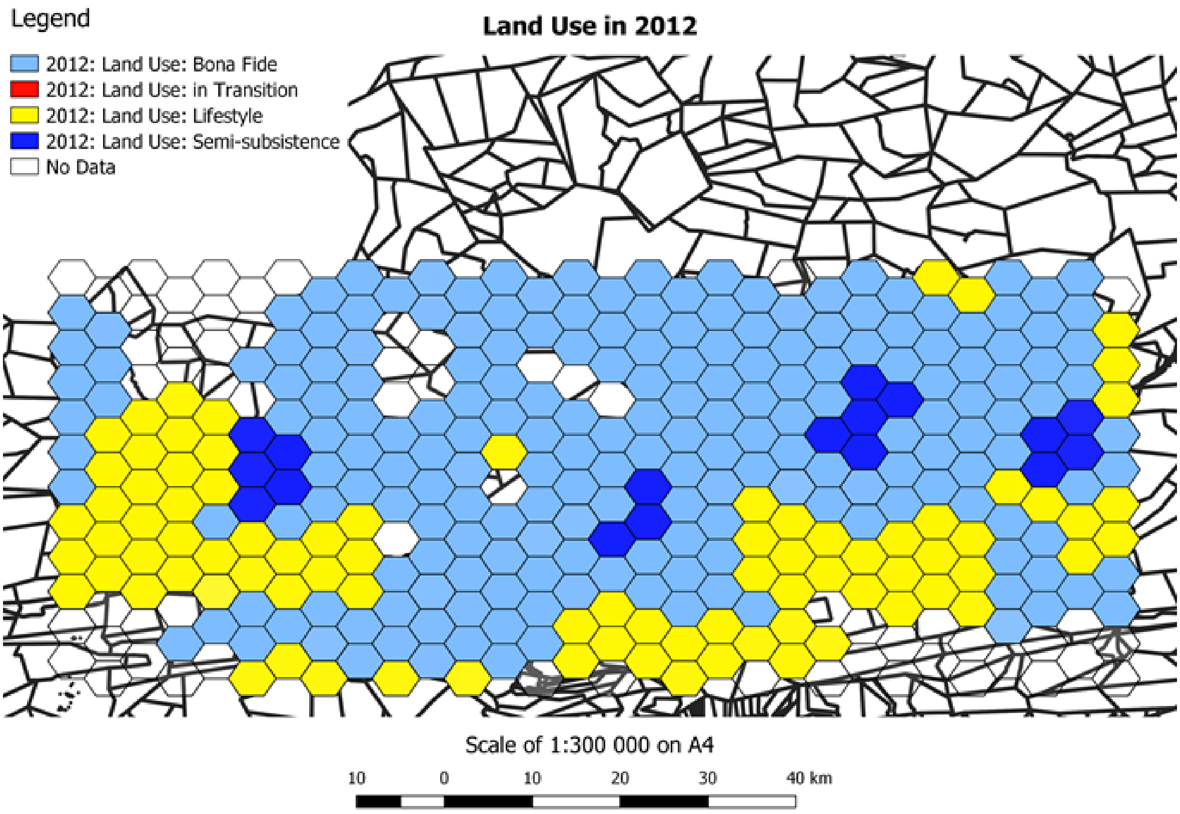
Location	Year	Rainfall % of expected	Heat stress Days >40°C	Efficiency %
Laingsburg village (39.5%)	2012	-13	3	68
	2013	-19	4	64
	2014	-10	0	65
Koup (34%)	2012	+49	7	78
	2013	-34	11	75
	2014	-8	4	71
Prince Albert village (8.5%)	2012	-20	11	71
	2013	+12	12	66
	2014	+35	13	61
Beaufort West village (18%)	2012	+57	0	78
	2013	+10	1	72
	2014	-2	1	67

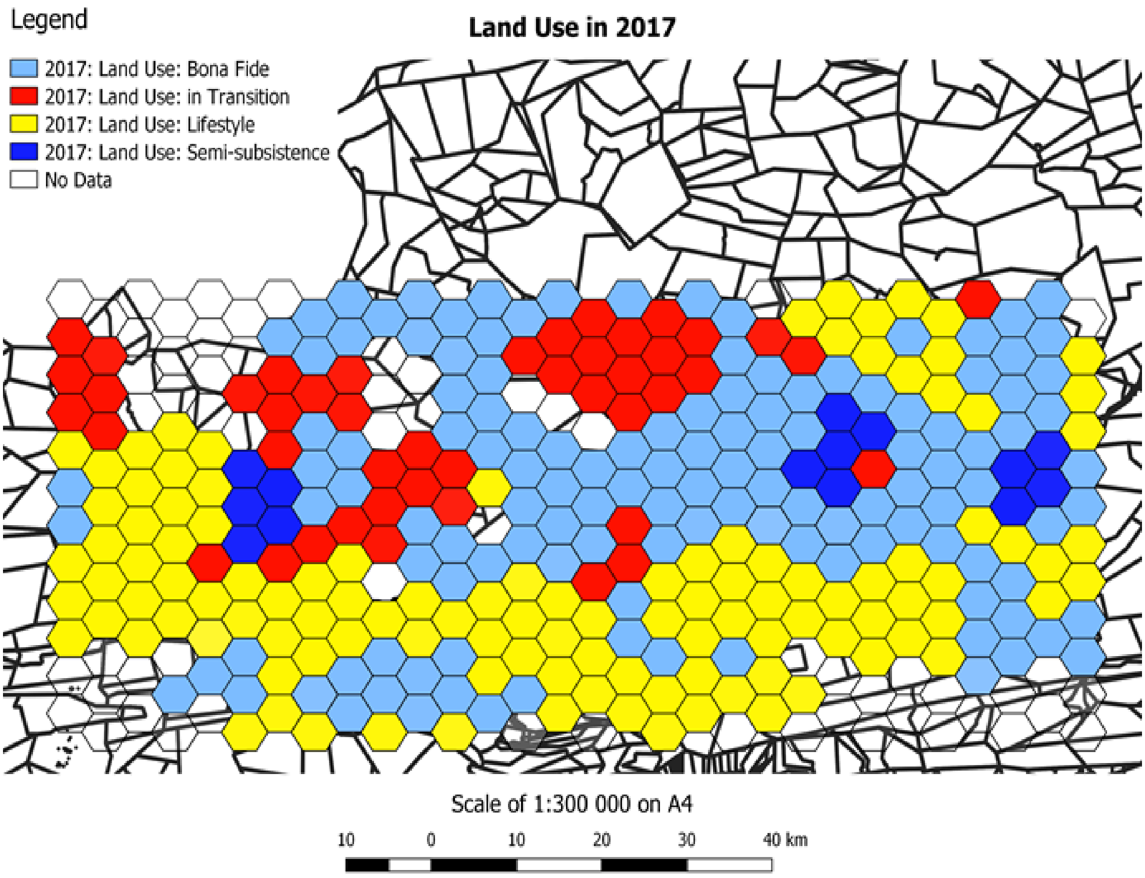
Table 5: OLS regression – dependent variable: the Kumbhakar efficiency score

Regressors	**Coefficient**	**Std Error (OLS)**	**dF/dx**	**Std Error (dF/dx)**
Rainfall%	0.255***	0.076	0.133***	(0.046)
Days > 40° C	0.004	0.003	0.004	(0.003)
Rainfall% x days > 40° C	-0.026**	0.011		
Constant	0.678***	0.019		
Observations	199		199	
Adjusted R-Squared	0.0468			
Model F-Test: Prob > F	0.0062**			

*** p<0.005, ** p<0.05.

Figure 2: Land use change in the Central Karoo, 2012 and 2017




Legend
2017: Land Use: Bona Fide
2017: Land Use: in Transition
2017: Land Use: Lifestyle
2017: Land Use: Semi-subsistence
No Data
Land Use in 2017
Scale of 1:300 000 on A4
10
0
10
20
30
40 km