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The odds of South African agriculture using wildlife ranching to adapt to climate change

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Abstract

In this paper, we explore the role of wildlife in climate change adaptation, especially in areas used predominantly for livestock production in South Africa. Using a sample of 3 449 wildlife and livestock ranches, we estimate a multinomial choice model of various ranching options in these areas. The results indicate that mixed wildlife-livestock ranches are less vulnerable to climate change when compared to ranches with only wildlife or only livestock. However, given the ranching options, the revenues of ranches with only wildlife are higher compared to other ranches. The results further show that an increase in temperature will influence more livestock farmers, especially those farming with cattle, to change their land use from livestock to wildlife ranching. Using climate models, we establish that livestock farmers in the Eastern Cape province of South Africa will be affected most by climate change and will subsequently change their land use.

Key words: adaptation, agriculture, climate change, wildlife ranching

1. Introduction

Although livestock farming has long been the most popular form of land use in Southern Africa, wildlife ranching is fast emerging as a viable alternative, particularly in dry and semi-arid regions. The production of beef is recognised to be particularly vulnerable to the severe effects of climate change (Seo & Mendelsohn 2008b). The fact that there are few suitable options for adaptation and mitigation is a significant drawback. Communities residing near protected wildlife areas, and commercial livestock ranchers, have employed temporary coping mechanisms or financial solutions to alleviate the negative consequences of climate change (Wiid & Ziervogel 2012). Some livestock ranchers have nonetheless managed to alter their use of land, for example by moving away from large stock (e.g. cattle) to small stock (e.g. sheep or goats), as a way of adapting to weather variability and climate change (Seo & Mendelsohn 2008b). It is also worth noting that wildlife ranching and wildlife conservancies are becoming more popular among communities and commercial cattle ranchers in other countries.

The increasing transition of land from crops and livestock to wildlife ranching, especially in South Africa, has been attributed to a loss of political power by the white-dominated livestock ranching sector, the end of subsidies to farmers, deregulation of the agricultural sector, and climate change (ABSA Group 2003; Van der Merwe *et al*. 2004). The emerging wildlife-based land use in areas traditionally considered arable or grazing land is a new trend that has been empirically investigated the least. Wildlife ranching may have a greater impact as one of the adaptive possibilities than is currently believed. Few studies connect the expansion of wildlife ranching as an adaptation technique to climate change, which has negatively affected agricultural and livestock output. Against this background, accurate quantification of the role played by wildlife as alternative land use is important.

The majority of studies on climate change and agriculture in Africa have concentrated on cattle and crops, paying little attention to the function of wildlife ranching. This is despite the close relationship between raising livestock and managing wildlife in various climates, such as raising beef and dairy cattle and raising tiny stock like merino sheep and angora goats (Langholz & Kerley 2006). It therefore is more plausible to hypothesise that mixed ranches emerged out of the need to adapt to climate change. With deteriorating conditions in livestock-based land use, most of these ranchers switched to wildlife ranching. Those who held onto mixed ranching could be explained by the seasonality of wildlife-based production, which contributes to the dominance of mixed ranching (Smith & Wilson 2002).

It is possible that the omission of wildlife from earlier studies may have produced biased results, e.g. underestimated or overestimated the effects of climate change on agricultural systems, especially those in the Southern African region. In this study, we examine the role of wildlife ranching as an adaptation strategy in the context of livestock and wildlife ranching. In so doing, the study adds to the existing literature on agricultural adaptation to climate change. We investigate popular land-use practices in the marginal zones, such as ranching with either livestock or wildlife, as well as mixed livestock-wildlife.

We argue that, contrary to the findings of earlier studies, which cited limited adaptation options in marginal areas, wildlife ranching could play an important role in adaptation. There are more than 10 000 wildlife ranches in South Africa, and many more farmers are moving in that direction – at a pace of 2% to 2.5% annually (Langholz & Kerley 2006; Dry 2010; Child *et al*. 2012). According to earlier forecasts by Seo and Mendelsohn (2008a), an increase from +2.5°C to +5°C above the existing temperature levels is likely to eradicate cattle ranches and substantially reduce sheep ranches in the Southern Africa region.

The remainder of this paper is organised as follows: In the next section, a review of the theoretical framework on land-use change is provided. This is followed by the development of an econometric specification of the model for estimation in Section 3, and the study ends with conclusions and recommendations in Section 4.

2. Methodology

2.1 Theoretical framework

A profit-maximisation model was adopted in this study, according to which a farmer maximises utility by allocating land to alternative uses and chooses a combination of farming practices that generate the highest profits. In agriculture, especially subsistence farming, profit-maximisation models are criticised on the basis that the assumption that farmers maximise profits may not necessarily be true (Barnett & O'Neill 2010; Rufino *et al*. 2011).

Commercial ranching, however, is based on the assumption that a farmer's main objective is profit maximisation, and therefore land-use management happens in pursuit of profits rather than the conservation motive. The latter usually breaks down because of market failure and the need for enterprises to remain viable to sustain operations. Furthermore, biophysical, economic and social factors are assumed to influence preference for a given land-use option. Although there are other drivers behind the observed choices, it is still plausible in this study to adopt the neoclassical profit-maximisation assumption, since ranchers derive income to sustain farm operations by choosing the right mix of activities. We examine a landowner's dilemma in a climate-impacted situation, which involves choosing whether to keep raising cattle, or to switch to wildlife ranching.

We assume a profit-maximising landowner with a parcel of land of size S that has multiple options, which can include livestock and wildlife, denoted by l and w respectively at all points in time, such that $l_i + w_i = S_i$. At each point in time, landowners choose how much land is allocated under each use to maximise the discounted present value of benefits less the cost of conversion. That is,

$$max_{\ alw} \int_{t=0}^{\infty} \left\{ \sum_{l=0}^{i} \sum_{w=0}^{W} R_{lw} S_w e^{-rt} - \sum_{l=0}^{i} \sum_{w=0}^{W} C_{lw}(a_{lw}) e^{-rt} \right\} dt, \tag{1}$$

subject to

$$\dot{S}_i = (a_{wl} - a_{lw}) \tag{2}$$

$$\sum a_{lw} \leq S_i \tag{3}$$

$$a_{lw} \geq 0, \tag{4}$$

where l and w are livestock and wildlife land uses respectively, S_i denoteS the stock of land at period i, a_{lw} represents the number of hectares converted from use l to use w at a point in time, R_w and R_l stand for net benefits from a hectare of land under land use w or l, and $C_{lw}\ (a)$ is the total cost of converting a hectare of land from use l to w.[1] The optimal solution for current value Hamiltonian with shadow prices is such that, if the marginal conversion costs are constant, the condition for conversion from use l to use w becomes:

$$\frac{R_w}{r} - C'_{lw}(a_{lw}) > \frac{R_l}{r} \tag{5}$$

The decision rule is that conversion from use l to use w is optimal if the expected discounted present value of an infinite stream of net returns to use w, less the conversion cost, is greater than the

[1] Note that biophysical factors such as precipitation, soil and temperature variations are allowed to influence conversion costs.

discounted present value of net returns from use l. This means that farmers choose the use with the highest return that maximises utility.

2.2 Empirical strategy

To address the research questions, we initially grouped the farmers into two categories, namely livestock farmers and wildlife farmers. Mixed wildlife-livestock farmers were considered as wildlife farmers at this stage. From the previous theoretical formulation, a landowner facing a land-use choice from l to w has a profit function:

$$\pi_i = max(R_w - rC_{lw}), \tag{6}$$

where π_i is the profit that accrues to farm *i*. Using the general random utility expression, we can represent the expected profit when the landowner moves from a given land-use allocation, for example l to w, as:

$$U_{lw} = R_w - rC_{lw} = \beta_i V_{ilw} + \varepsilon_{ilw}, \tag{7}$$

where U_{lw} is the utility a farmer whose land is in use l gets by changing the land to use w, V_{ilw} is a vector of observed variables, β_i, are parameters, and ε_{ilw} is the error term. In this analysis, our interest is in the farmer's decision on land-use change at certain locations relative to both options. Thinda *et al*. (2020) use a zero-inflated double hurdle model to estimate the drivers of adaptation strategies and the intensity of adoption at the household level in South Africa. They find that different socioeconomic and institutional factors, such as gender, age, farmer's experience, access to extension services and climate change information, significantly influence the adoption of climate change adaptation strategies among the beneficiaries of land reform in South Africa. Our hypothesis is that the factors that drive land-use choices within the livestock sector could as well drive land-use change decisions from livestock to wildlife.

A dichotomous specification of the dependent variable converts location *i* into wildlife and non-wildlife use. Since preference for location cannot be observed, the preferred statistical model is thus a discrete probit model of two choices. We derive this from the underlying latent variable model:

$$y^* = \beta_0 + x\beta_1 + \varepsilon \tag{8}$$

and

$$y = 1(y^* > 0) \tag{9}$$

y^* is the latent variable, x denotes the set of explanatory variables, ε is the error term with the properties $N(0, \sigma^2)$, and $1[\, y * > 0]$ defines the boundary outcome. Having confirmed the drivers of land-use choices based on a dichotomous specification, we now compare the choice of farming system in the second stage, which includes wildlife and integrated wildlife-livestock farming, to those who only practise livestock farming. The choice that a farmer makes is assumed to be one that has the highest net revenue. Therefore, conditional on the farmer's choice, we estimate the net revenue of the chosen enterprise. The basic model is given by:

$$Y_i = X_i\beta_i + \varepsilon_i \tag{10}$$

$$Y^*{}_s = Z_s\gamma_s + \eta_s, \tag{11}$$

where Y_i refers to the net revenue per hectare associated with a specific farming choice (livestock, wildlife or mixed wildlife-livestock), $Y^*{}_s$ is a discrete choice variable indicating the categories of different farming choices, X_i and Z_s are explanatory variables that include biophysical factors, as well as economic and social factors, and ε_i is the disturbance term with the usual properties. This model can be estimates using OLS by running each revenue equation separately. But there are problems of unobserved characteristics that affect both the choice of the ranching type and the generated revenues. This implies that the error terms ε_1 and η_s will be correlated, and the estimated β_i will be inconsistent.

For the selection bias correction in the multinomial logit models, we follow an approach originally developed by Dubin and McFadden (1984), and later extended by Bourguignon *et al*. (2007). The extended model adopted in this study assumes a linear association between ε_i and η_s, i.e. $\varepsilon_i = \sigma_i \sum \rho_s \eta_s * + \omega_i$. The residual term is orthogonal to all η_s*: the bias-corrected net-revenue equation thus becomes:

$$Y_i = X_i\beta_i + \sigma_i \left[\rho_i m(P_i) + \sum \rho_s \frac{P_s}{(P_s - 1)} + m(P_s)\right] + v_i, \quad (12)$$

where P_s is the probability that a category s is chosen, $v_i = \eta_i + \log P_i$, and ρ_s is the correlation coefficient between error terms ε_i and v_i. Estimates of σ_i in the above equation are consistent. The second term in the right-hand equation corrects for the selection bias. This term explains the interactions between livestock, mixed wildlife-livestock farms and wildlife-only farms. The number of bias-correction terms in the equation is equal the number of choices. The methodology allows us to identify not only the direction of the bias related to the choice of system, but also which choices between any two alternative systems the bias stems from. The violation of the independence of irrelevant alternatives (IIA) assumption, or the presence of non-linear specification, does not limit the model (Dimova & Gang 2007).

2.3 Data and sample size

This study combines the 2007 census for commercial agriculture in South Africa (StatsSA 2010), climate variables obtained from the Climate System Analysis Group,[2] and soil data for seven provinces (Eastern Cape, Limpopo, Northern Cape, Free State, Mpumalanga, North West and Western Cape) from the Food and Agriculture Organization (Gbetibouo & Hassan 2005). Both climate and soil variables were clustered at the district municipality level using geographical information systems.

In total, 39 966 farms were enumerated, capturing both the production and financial activities of all commercial farmers in the agricultural census. Since the study was interested in livestock and wildlife activities, the focus therefore was on these two sub-sectors of agriculture. It should be noted, however, that reporting on wildlife utilisation is yet to be fully captured during the census periods. This is a serious limitation for studies focusing on the wildlife-game subsector. We identified 3 449 ranches with wildlife and livestock across six provinces. The data from the six provinces represents over 80% of farming activities in South Africa.

The dependent variables include the binary and mutually exclusive categories of ranches. In this case, 1 indicates the presence of either wildlife or livestock on the ranch, and 0 indicates their absence. Where one is present, it means that the other is absent because they are mutually exclusive. There are three sets of independent variables. The first set includes biophysical elements, which include

[2] Downloaded from http://cip.csag.uct.ac.za/webclient2/data sets/africa-merged-cmip5/ on 26 August 2014.

temperature, precipitation and soil variables. The second set includes economic variables such as land size, and dummy variables for ranches that purchase water, intervene during droughts by providing water, pasture relief and medication, and rent extra spaces for grazing, along with the classification of farms according to income categories.[3] The third set includes social factors, such as social networking through membership of and affiliations with relevant groups. Finally, we also controlled for regional fixed effects.

3. Results and discussion

3.1 Descriptive statistics

Table 1 provides an overview of the descriptive statistics of the key variables used in the study. Four categories of ranches are described: wildlife-only ranches, mixed wildlife and livestock ranches, mixed livestock ranches (sheep and cattle), and sheep-only ranches. These are the more dominant livestock enterprises in marginal areas. A parametric test of statistical significance was undertaken to determine the mean differences between the four categories. The results of the test rejected the null hypothesis of no difference, suggesting that the true difference in means is not equal to zero.

Across the four categories of ranches, the average net revenue from wildlife-only ranches was lower that that from the other ranches. This is in contrast with the expectation that revenue per hectare of wildlife land used should be higher (Dry 2010). The revenue of ranches with sheep only is higher compared to other ranches. Except for goat meat, which is expensive in South Africa, the price for mutton is higher in the market compared to beef and game. However, in the sample used, the wildlife ranches (4 632.0 ha) are slightly smaller than mixed livestock-wildlife ranches (5 063.7 ha), but larger when compared to livestock-only ranches, i.e. ranches with cattle and sheep (4 079 ha) and with sheep only (2 073 ha). The land sizes for mixed livestock-wildlife ranches are on average higher when compared to livestock- and wildlife-only ranches. One would expect this to be the case, since more land is required in areas where wildlife husbandry has to coexist with livestock. A higher number of mixed ranches and wildlife ranches have a high turnover, at 6% and 3.5% respectively, compared to livestock ranches at 2.9%.

Farmers in Africa rely heavily on rain-fed agriculture (Seo *et al*. 2009). Therefore, in terms of water, the analysis shows that wildlife ranches rely more on naturally existing water sources. A few ranches purchase water or rely on bulk water storage, unlike the case for livestock farms. Around 3% of wildlife ranches purchase water, while 5% rely on either boreholes or abstraction from river sources. Compared to 39% of the livestock ranches, 32% of wildlife ranches intervene by providing supplementary water and feeds during drought episodes.

[3] StatsSA classifies commercial farms into four distinct income groups based on annual turnover: R5 000 000 and more (income group 1); R3 000 000 ≤ N < R5 000 000 (income group 2); R500 000 ≤ N < R3 000 000 (income group 3); and 0 ≤ N < R500 000 (income group 4).

Table 1: Descriptive statistics for wildlife and livestock ranches

Variable/farm types	Only wildlife – no livestock	Both wildlife and livestock	Only sheep	Mixed livestock – cattle and sheep
Land size (ha)	4 631.955 (12 559.7)	5 063.7 (11 136.7)	2 073 (3 128)	4 079 (6 805)
Net income per ha (rand)	91.73 (53.96)	91.12 (52.41)	98.51 (51.85)	92.51 (51.62)
Ranches paying abstraction fee	0.045 (0.21)	0.095 (0.29)	0.049 (0.22)	0.092 (0.29)
Ranches purchasing water	0.030 (0.17)	0.117 (0.32)	0.103 (0.30)	0.086 (0.28)
Ranches with membership of associations	0.418 (0.45)	0.529 (0.50)	0.408 (0.49)	0.480 (0.50)
Ranches renting grazing land	0.134 (0.34)	0.353 (0.48)	0.276 (0.45)	0.381 (0.49)
Ranches purchasing remedies for drought	0.328 (0.47)	0.670 (0.47)	0.564 (0.50)	0.607 (0.49)
Farm categories by revenue	0.067 (0.25)	0.063 (0.24)	0.013 (0.11)	0.048 (0.21)
Soil: Fluvisols	0.403 (0.49)	0.488 (0.50)	0.611 (0.49)	0.344 (0.48)
Soil: Ferralsols	0.522 (0.50)	0.307 (0.46)	0.056 (0.23)	0.202 (0.40)
Soil: Lixisols	0.940 (0.24)	0.760 (0.43)	0.784 (0.41)	0.729 (0.44)
Soil: Arenosols	0.664 (0.47)	0.506 (0.50)	0.722 (0.45)	0.366 (0.48)
Soil: Luvisols	0.455 (0.50)	0.692 (0.46)	0.674 (0.47)	0.774 (0.42)
Soil: Leptosols	0.947 (0.22)	0.936 (0.24)	0.824 (0.38)	0.834 (0.37)
Soil: Durisols	0.701 (0.46)	0.805 (0.40)	0.800 (0.40)	0.740 (0.44)
Average annual temperature	26.26 (2.16)	24.83 (2.37)	25.04 (2.38)	23.78 (2.2)
Average annual rainfall	47.01 (12.76)	42.10 (12.33)	26.24 (14.11)	44.59 (14.50)
Total number of ranches	**134**	**221**	**1 212**	**1 882**

Note: This table presents summary statistics for the dependent variables and continuous variables in the sample. For each variable we have the overall mean and standard deviation, as well as the number of observations.

While ranches are found across all the regions of South Africa, a significantly higher number of wildlife-only, livestock-wildlife, and livestock-only ranches are located in areas where the dominant soil types are characterised by leptosols and lixisols. Mixed livestock-wildlife ranches are in areas where the soil is characterised by leptosols and durisols, while most livestock-only ranches are in areas with large amounts of leptosols. According to the Food and Agriculture Organization of the United Nations (2015), lixisols under savannah vegetation are often used for low-volume grazing. Leptosol soil is unattractive for arable cropping, and has limited potential for tree crop production or extensive grazing. Durisols can only be used for extensive grazing. Finally, luvisols with good internal drainage are potentially suitable for a wide range of agricultural uses because of their moderate stage of weathering and high base saturation.

In terms of the location of ranches based on climatic conditions, most wildlife ranches are located in areas that are comparatively hotter in both summer and winter when compared to livestock and mixed ranches. On average, temperatures in these areas are above 22.6°C and can reach as high as more than 29.2°C on average. A comparison of the three farming options in terms of climate variables suggests that the location of wildlife ranches is highly correlated with climate conditions. There is not much difference in precipitation during summer, however, although areas predominantly occupied by wildlife seems to be those areas where there is less winter rainfall.

3.2 Empirical results

The analysis begins by evaluating the determinants of land-use change using a probit model, as presented in Table 2. The dependent variable is a binary variable of wildlife and livestock ranches, i.e. whether or not a rancher has wildlife. In this case, mixed livestock-wildlife ranches are considered alongside wildlife ranches. The independent variables include climate variables, soil variables, land size, social networks and a set of dummy variables representing geographical regions.

Table 2: Probit model of average partial effect on land-use change

Variable	Coefficient	Standard error	Average partial effect
Land size	0.086***	(0.031)	0.011
Annual temperature	1.653***	(0.390)	0.214
Annual temperature square	-0.030***	(0.008)	-0.004
Annual precipitation	0.075***	(0.015)	0.010
Annual precipitation square	-0.001***	(0.000)	-0.000
Membership/affiliation	0.153**	(0.071)	0.020
Remedies drought	-0.064	(0.069)	-0.008
Rental grazing	-0.084	(0.076)	-0.011
Soil: Fluvisols	0.118	(0.102)	0.015
Soil: Ferralsols	0.152	(0.130)	0.021
Soil: Arenosols	-0.163*	(0.098)	-0.021
Eastern Cape	0.402***	(0.130)	0.063
Free State	-0.288**	(0.112)	-0.034
Limpopo	1.640***	(0.192)	0.467
Constant	-26.13***	(4.032)	
Observations	**3 449**		
LR chi^2	151.55		
Prob/chi^2	0.0000		
R^2	0.1599		

Notes: The table reports coefficients of the probit data estimators. The dependent variable is binary, obtained by dichotomising farms into wildlife and livestock farms. Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All predictors are at their mean value.

The probit results show that both rainfall and temperature have a significant correlation with the transition of ranchers from livestock to wildlife, as shown by the hill-shape non-linear term. The results also show that a rancher is likely to consider transitioning from livestock to wildlife ranching with increasing temperatures and decreasing rainfall.

The size of land is known to motivate private landowners to consider different conservation behaviours (Lambert *et al*. 2007). This is expected, since ranchers with large tracts of land are more likely to consider integrated wildlife-livestock ranching. Ranchers in this group will eventually transition to wildlife-only ranching. Another influential determinant of land-use change is membership of or affiliation with social networks. The results show that ranchers in this group are more likely to be influenced into changing land use. The role of collective power would probably motivate a livestock rancher to change his use of land and to enjoy the benefits of self-regulation and bargaining.

When we control for regional heterogeneity by including the provinces in the model, our results show that ranchers in Limpopo and the Eastern Cape are more likely to prefer either mixed-wildlife ranching or wildlife ranching to livestock-only ranching. Most wildlife ranches are located in areas that are comparatively hotter in both summer and winter when compared to the location of livestock ranches. Limpopo province is known to be hot and has half the total number of wildlife ranches and wild animals outside the protected areas.

Livestock ranchers in the Free State are less likely to prefer wildlife ranching. This is expected, because the Free State is largely arable, contributing 32% of total arable land in South Africa (Benhin 2008). In areas such as the Eastern Cape, ranchers are likely to move to wildlife farming,[4] as the area generally receives poor rains. In addition, the farmers are more commercially oriented, with 13% of all commercial farmers in the country coming from the Eastern Cape province. Biophysical and climatic conditions make farmers in Limpopo almost twice more likely to move to wildlife ranching compared to ranchers in a province such as the Eastern Cape. The study therefore presents factors that would influence farming activities in the marginal areas. The conclusion at this point is that rising temperatures and declining rainfall will influence revenue and the choice of activities.

3.3 The role of wildlife in land-use choices: A multinomial logit approach

There is potential for the need for land-use change in the future because of climate change, and this will alter the way farmers utilise their land (Seo 2010). The analysis progressed in two stages: in the first stage we used a multinomial logit regression to model the determinants of ranching choices. The available choices include ranches with only wildlife, ranches with livestock and wildlife, ranches with mixed livestock, and finally ranches with only sheep. The first step not only provided insight into the determinants of choice of ranching systems under the existing options, but also generated selection bias correction terms for the second stage, in which the conditional revenue equation is evaluated.

The identification of adaptation responses is known to be prone to omitted viable bias (Wang *et al*. 2014). Before proceeding to analyse the choices, diagnostic tests were conducted. According to Long and Freese (2006), this means testing that all the coefficients associated with an independent variable are simultaneously equal to zero, that is, testing that a variable has no effect. Next, we tested whether the independent variables differentiated between two outcomes, i.e. if two outcomes can be combined. Finally, we tested for the assumption of the independence of irrelevant alternatives. The results of the Wald test in Table 3 show that the independent variables used in the study are simultaneously equal to zero. The results further reveal that the categories are independent and therefore could not be collapsed. A test for IIA carried out using the Small-Hsiao approach showed that IIA was not violated.

[4] They are likely to farm with small plain game as opposed to large mammals and big cats due to the limited pasture for big game.

Table 3: Wald test for independent variables

Variable	chi^2	Degrees of freedom	P > chi^2
Land size (ha)	115.95	3	0.000
Net income/ha (rand)	15.921	3	0.001
Ranches with membership of associations	9.963	3	0.019
Remedies for drought	49.539	3	0.000
Ranches renting grazing land	13.314	3	0.004
Ranches purchasing water	6.873	3	0.076
Average annual temperature	1.007	3	0.800
Average annual temperature (squared)	1.965	3	0.580
Average annual rainfall	314.98	3	0.000
Average annual rainfall (squared)	148.38		0.000
Fluvisol soil	29.244	3	0.000
Ferralsol soil	13.254	3	0.004
Lixisol soil	0.004	3	0.000
Arenosol soil	22.056	3	0.000
Constant	13.312	3	0.004
Set_1: Test of average temperature as a set	154.495	6	0.000

Notes: H_0 = All coefficients associated with the given variable(s) are 0. The test of the temperature variable was not significant. However, tested as a set (allowing the non-linear component of temperature into the model), the Wald test for the temperature variable was statistically significant.

3.4 Multinomial choice results

The decision made by a rancher when choosing one of the available options was estimated, and the reference category was given as wildlife-only ranches. From the results in Table 4, it is clear that the size of the land increases the odds of selecting mixed wildlife ranching over wildlife-only ranches by 44.7%. The odds of a mixed livestock-wildlife rancher with a large revenue base moving to wildlife ranching reduces by 21% compared to those with smaller revenue bases. Ranches with smaller revenues are more likely to transit to wildlife-only ranching, as they consider wildlife ranches to have low production costs, given the ability of wildlife to withstand higher temperatures and lower rainfall. The odds of a rancher choosing wildlife ranches over livestock or sheep decrease with precipitation. When ranchers are faced with drought, those who purchase supplementary feeds, water and medicine for drought mitigation are four times more likely to remain in mixed wildlife ranching than those who do not. The implication of this is that, instead of land-use change over the short term, ranchers are able to adopt these coping strategies to deal with drought.

Where ranchers are in areas that are characterised predominantly by lixisols, the odds of choosing wildlife-only ranching increases across all the ranches. However, where soils are predominantly luvisols, the odds of choosing sheep farming over wildlife-only ranching increases more than three times. Luvisol types of soil are conducive for a wide range of agricultural activities, and therefore there is a comparative advantage in having sheep as opposed to wildlife.

Table 4: Results of the multinomial logit choice model

Variable	Wildlife and livestock – Odds ratio	Mixed wildlife – Odds ratio	Sheep – Odds ratio
Land size	1.447*** (0.184)	1.259** (0.138)	0.735*** (0.085)
Farm category by revenue	0.211*** (0.126)	0.212*** (0.110)	0.540 (0.319)
Membership/affiliation	0.804 (0.208)	0.594** (0.137)	0.532*** (0.129)
Remedy for drought	4.292*** (1.083)	3.659*** (0.816)	2.557*** (0.599)
Rental grazing	2.121** (0.679)	2.287*** (0.670)	1.754* (0.534)
Purchase of water	3.831** (2.283)	2.687* (1.538)	3.252** (1.897)
Mean annual temperature	0.794 (0.737)	0.698 (0.594)	1.040 (0.946)
Mean annual temperature squared	0.998 (0.026)	0.991 (0.023)	0.976 (0.025)
Mean annual precipitation	0.969 (0.051)	0.833*** (0.037)	0.633*** (0.029)
Mean annual precipitation squared	1.000 (0.000)	1.001*** (0.000)	1.004*** (0.000)
Soil: Fluvisols	0.699 (0.216)	0.325*** (0.088)	0.351*** (0.101)
Soil: Lixisols	0.264*** (0.116)	0.318*** (0.132)	0.414** (0.178)
Soil: Ferrasols	2.281** (0.925)	0.747 (0.264)	1.342 (0.537)
Soil: Luvisols	1.770 (0.660)	1.509 (0.478)	3.118*** (1.064)
Constant	146.8 (1 251)	6.547** (5.095)	7.123*** (5.858)
Observations	**3 449**	**3 449**	**3 449**
LR chi^2	557.25		
Prob > chi^2	0.0000		
Pseudo R^2	0.3087		

Notes: The multinomial logit choice model gives the choice spectrum a rancher has, conditional on the various climate, soil and farm-specific variables. The base category is wildlife-only ranches: All predictors are at their mean value, and standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.

3.5 Vulnerability of various ranching systems to climate change

Which of the available choices of ranching is more vulnerable to climate change? This empirical question deserves attention. The vulnerability of each of the ranch type can be determined by calculating the change in the marginal effect on the decision to choose a specific ranch when the system is disturbed by a 1°C increase in temperature or a 1% decrease in precipitation (Seo 2010). The results are presented in Table 5.

Table 5: Marginal effects of the choice probability of each ranching system (%)

		Wildlife, no livestock (%)	Wildlife and livestock	Mixed livestock, no wildlife	Sheep only
Baseline	Temperature (°C)	0.22	-0.03	-8.4	8.2
	Precipitation (mm/month)	0.25***	1.27***	4.73***	-6.2***
1°C increase in temperature and 1 mm increase in precipitation	Temperature (°C)	0.67	-0.07	-6.1	5.56
	Precipitation (mm/month)	0.56***	1.1***	2.4***	-4.1***

Note: The table shows the marginal change in the probability of choosing a ranching system given a small change in temperature or precipitation over the current levels.

A 1 mm decline in precipitation over the current level will increase the probability of farmers choosing wildlife and mixed wildlife ranching over sheep ranching. Consistent with the theory and expectations, the results further show that more farmers would prefer integrated ranching over a single species. Even though an increase in temperature is likely to influence ranchers to prefer either wildlife or sheep ranching, this influence is not significant with a one degree increase in temperature.

3.6 Estimation of conditional net revenue of wildlife ranches

If a rancher has chosen one of the ranching options, the rancher can maximise net revenues by choosing the appropriate level of inputs and outputs. After accounting for the selection bias of individual farmers into the categories, we could estimate the conditional revenue equation for each option. The interest in this analysis is in the selection bias coefficient represented by M0 to M3, which are the Bourguignon *et al*. (2007) equivalents for the Mills ratio. The terms show the interactions among the three systems of ranching discussed.

Table 6 shows the results of the conditional net revenue estimation. The selection bias correction coefficient of wildlife farms was positive and significant for the choice of mixed livestock-wildlife ranching. This essentially shows interaction between these farm enterprises. More specifically, it implies that, holding other factors constant, farmers practising mixed livestock-wildlife ranching were on average more likely to make higher profits if they were to choose wildlife-only ranching. In the case of sheep ranching, the sign was negative and significant, which implies that, holding other factors constant, sheep farmers are likely to make less profit if they were to move to wildlife ranching. The study further reveals that livestock ranches would make more profit if the ranchers were to move to mixed livestock-wildlife ranching. If sheep ranchers were to consider transitioning to mixed livestock ranches, the negative sign for sheep ranching would indicate that they would make significant losses. The results of the conditional net revenue analysis support the multinomial choice results. Even though mixed livestock-wildlife ranches are less vulnerable to a small climate-change perturbation when compared to wildlife-only ranching, the conditional net revenue results suggest that wildlife-only ranches are likely to be more profitable in the current climate scenario when compared to livestock ranches.

Table 6: Conditional net revenue estimation

Variable	Wildlife – no livestock	Mixed ranches	Mixed livestock	Sheep only
Annual temperature	-0.192 (1.067)	0.485 (0.651)	-0.259 (0.169)	-0.204 (0.313)
Annual temperature squared	0.014 (0.022)	-0.006 (0.012)	0.008** (0.003)	0.005 (0.006)
Annual precipitation	0.128* (0. 075)	0.000 (0.045)	-0.012 (0.015)	-0.019 (0.013)
Annual precipitation squared	-0.001* (0.000)	-0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Soil: Luvisols	0.077 (0.466)	0.102 (0.294)	0.285** (0.112)	0.142* (0.081)
Soil: Durisols	-0.387 (0.239)	-0.130 (0.164)	0.209*** (0.061)	0.052 (0.091)
Soil: Lixisols	0.415 (0.662)	-0.076 (0.314)	-0.206** (0.105)	0.091 (0.094)
Large farms	0.537 (0.488)	0.306 (0.335)	0.252 (0.172)	0.541 (0.215)
Remedy for drought	-0.212 (0.136)	-0.100 (0.122)	0.032 (0.043)	0.031 (0.049)
_m0 (wildlife-only ranches)		0.623** (0.325)	0.163 (0.479)	-1.353*** (0.526)
_m1 (mixed wildlife ranches)	2.237 (3.923)		3.650*** (1.208)	1.162 (1.121)
_m2 (mixed livestock ranches)	-0.490 (1.974)	-0.038 (2.496)		-0.791* (0.465)
_m3 (sheep ranching)	-0.827 (1.618)	1.888 (1.208)	1.230*** (0.434)	
Constant	1.618 (15.157)	-4.192 (11.070)	7.324*** (2.058)	6.381 (3.921)
rho0	0.380** (0.182)	0.990* (0.553)	0.069 (0.288)	-1.181*** (0.422)
rho1	1.364 (1.079)	0.366* (0.194)	1.541*** (0.385)	1.015 (0.798)
rho2	-0.298 (0.616)	-0.023 (0.780)	-0.049 (0.092)	-0.690** (0.338)
rho3	-0.504 (0.587)	1.151** (0.478)	0.519*** (0.184)	-0.134 (0.120)

Notes: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All predictors at their mean value. _M0, _M1, _M2 and_M3 are the BFG equivalents for the Mills ratio, related to wildlife, mixed wildlife ranches, mixed livestock ranches and sheep ranches respectively.

3.7 Projected land-use change in the arid and semi-arid areas

In this section, farmers' decisions to change land use is measured in different climate scenarios. This was done using the difference in the probability of choosing land use before and after climate change for each climate scenario. The projections for the climate scenarios use three atmosphere-ocean global circulation model (AOGCM) climate scenarios. These include the Commonwealth Scientific and Industrial Research Organization (CSIRO2), the parallel circulation model (PCM) and the Hadley Centre coupled model (version 3) (HadCM3). These models have been used in the literature for South Africa (Benhin 2008). The model predicts a temperature increase of between 2.9 and 9 degrees over the period 2050 to 2100. It also predicts a decline in precipitation of between 2% and 15% over the same period. The predicted change in choice of land use as temperature and precipitation for South Africa change is presented in Table 7.

As seen from the results in Table 7, climate change will cause adjustments across the different models, especially among livestock farmers. As the temperature increases, the coupled general circulation model (CGCM2) predicts that mixed livestock-wildlife ranchers would prefer to move to wildlife-only ranching. The CGCM2 predicts that, in 2050, up to 3.3% of current mixed livestock-wildlife ranchers would have moved to wildlife-only ranching. HadCM3 predicts a slightly higher desire for adjustment, especially in the light of temperature increases. What is also fundamental to note is that, with declining precipitation, several ranchers who practise mixed livestock-wildlife ranching would probably move to wildlife- only ranching. In the case of livestock, especially sheep farms, it is the increasing temperatures that may motivate ranchers to move to wildlife ranching. However, declining rainfall reduces the probability of them changing to wildlife. This can be explained by the nature of the environment in which they operate. Most sheep ranchers face similar environmental condition as wildlife ranchers and, if the amount of rain declines, it means that even wildlife ranchers are facing similar conditions, and no comparative advantage is obtained by shifting. Unlike temperature, this affects the animals directly and there is less of an option for intervention. Therefore, these ranchers will consider moving to wildlife ranching as the best option.

The results of ranches with mixed livestock show similar patterns. Since the mixed livestock ranches in this study are those ranches with cattle and sheep, it is possible that the probability of moving to wildlife ranching declines with precipitation because ranchers can easily reduce their stocks of cattle and increase those of sheep as a way of adaptation. With temperatures increasing by up to about 2.5%, the cost of short-term interventions probably may be overwhelming, thereby necessitating a shift to wildlife ranching.

Table 7: Percentage increase in the probability of land-use change

	Climate	**CGCM2 2050**	**CGCM2 2100**	**PCM 2050**	**PCM 2100**	**HadCM3 2050**	**HadCM3 2100**
Wildlife and livestock	Temperature	3.29	3.63	3.21	3.42	3.31	3.67
	Precipitation	1.13	1.19	1.11	1.13	1.18	1.28
Mixed livestock – no wildlife	Temperature	2.45	2.56	2.40	2.45	2.56	2.77
	Precipitation	-7.23	-8.35	-6.96	-7.64	-7.29	-8.48
Livestock – sheep only	Temperature	1.19	1.79	1.04	1.41	1.22	1.86
	Precipitation	-4.26	-4.44	-4.17	-4.26	-4.44	-4.81

Note: These are percentage changes. The table captures a change from mixed ranching and livestock ranching to wildlife ranching under the three different climate scenarios projected for 2050 and 2100.

4. Conclusions and recommendations

Over time, some farmers have changed their land use from livestock ranching to wildlife due to climatic or non-climate factors. However, much of the ongoing discourse in South Africa suggest that land-use change from livestock to wildlife has had more to do with the politics of land restitution claims in the post-apartheid era than with climate change. Our study confirms that the observed changes in land use among ranchers could just as well be linked to factors responsible for land-use change in the agricultural sectors.

Is wildlife ranching recognised as a significant sub-sector within the institutional framework for administering the agriculture sector? The model predicts that these factors may enhance farmers' inclination to join the wildlife-ranching sub-sector in marginal areas as the temperature rises, along with enhancing the growth of the sector. The Eastern Cape province has the highest number of livestock farms and plays a very important role in beef production and food security. However, as cattle ranchers transition to alternate land uses, it is also in these places that the most adjustments are expected to occur. Therefore, there is a need to focus attention on the sustainable growth of both wildlife and livestock in the marginal areas. While previous studies predicted warming to have greater effects on large livestock farms, our analysis reveals that wildlife land use will provide an alternative land-use option. Linking wildlife and agriculture provides a sustainable land-use option in the marginal areas, which could be good for conservation. Good policies can generate adequate incentives for farmers to protect wildlife and to increase the supply of habitat.

It therefore is necessary to incorporate wildlife as an alternative land-use option to increase adaptation to climate change in agriculture. Wildlife ranching competes directly with other land-based options such as crop and livestock. Legal and institutional frameworks in South Africa recognise wildlife ranching as one of the sub-sectors of agriculture. There is an urgent need to reconfigure climate change policies on mitigation and adaptation in agriculture to embrace wildlife ranching.

Given the multiple uncertainties related to crop, livestock and wildlife use in the face of climate change, resilience will depend on successful adaptation. Options for pro-poor resilience in livelihoods include policies on improved social protection, improved water and land governance, improved tenure security over land to avoid conflict, enhanced water storage and encouraging greater involvement by communities in the use of wildlife resources. There is a need to design development and adaptation policies and initiatives that adopt a longer-term view and consider the multi-stressor context to avoid maladaptation or outcomes that may serve short-term goals, but with some future cost to the society. It is important to appreciate a number of possible limitations of the study. Firstly, agricultural data for 2007 was collected at a time when the country was experiencing drought. It is possible that the effects of drought could have been reflected in the profitability of firms and farming practices. Secondly, reporting on game-farming activities has not picked up to a significant level. The farmers whose views were captured during this reporting period may not necessarily be representative of all farmers, especially those who never provided their farming information.

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