Agriculture and adaptation to climate change: The Role of wildlife ranching in South Africa

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Abstract

In this paper, we explored the role of wildlife in adaptation to climate change in areas predominantly used for livestock production in South Africa. Using a sample of 1071 wildlife and livestock farms we estimated a multinomial choice model of various adaptation options including livestock and wildlife farming choices. The results indicate that mixed livestock-wildlife farms are less vulnerable to climate change when compared to specialized livestock or wildlife farms. However, net farm revenues per hactare are higher for specialized wildlife ranches when compared to mixed wildlife-livestock ranches or livestock ranches. The results further show that temperature increase will influence most livestock farmers to change land use to wildlife ranching. At farm level, land size and social networks are also likely to play a bigger role in land use change as climate changes. Using climate models, we establish that livestock farmers in Eastern Cape Province of South Africa will be most affected by climate change and will subsequently change land use.

JEL Classification: Q12; Q15; Q54

Keywords: Climate change; Wildlife Ranching; Adaptation; Agriculture; South Africa

1 Introduction

In the arid and semi-arid areas of Africa, some of the most common land uses remain in pastoralism or in some cases commercial livestock ranching. Agricultural activities in these areas especially beef production is known to be highly vulnerable to the severe effects of climate change, (Seo et al., 2008). However, a major limitation is that appropriate adaptation and mitigation options are few. Therefore, both commercial farmers and communities faced with climate related challenges can only use temporary coping mechanisms or financial solutions to

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mitigate adverse effects of climate change, (Wiid and Ziervogel, 2012). Some farmers nonetheless have managed to alter use of land for example by moving away from bigger animals such as cattle to smaller stock such as sheep or goats, (Seo and Mendelsohn, 2008) as a way of adapting to weather variability and climate change. In other regions of Africa such as Southern Africa region, commercial farmers and communities are moving land away from livestock use to wildlife utilization especially wildlife ranching, wildlife farming or wildlife conservancies. The emerging wildlife-based land use in areas traditionally considered arable or grazing land is a new trend that less empirical investigation has been carried on. Therefore accurate quantification of the role played by wildlife as alternative land use is important.

It is also important to note that wildlife ranching is likely to play a key role in terms of wildlife conservation given the uncertainties created by climate change in the public protected areas, (Von Maltitz et al., 2006). In the case of South Africa, climate change has exposed more species of wildlife into extinction, (Thomas et al., 2004; Erasmus et al., 2002). Erasmus et al., (2002), find that up to 66 per cent of the 179 species in their study on Kruger National Park will be lost due to climate change. Thomas et al., (2004) predict that between 15-35 per cent of species in their sample would be at risk of extinction. But expansion of public protected areas to protect more wildlife is considered almost impossible due to the cost involved, therefore few remaining options for conservation are outside the protected areas such as ex-situ conservation options (IPCC, 2013) or wildlife ranches and conservancies, (Von Maltitz et al.,2006).

Against this background, linking wildlife utillization to livestock production in the marginal areas as an opportunity for wildlife conservation as well as economic outcomes is important. In most studies on climate change and agriculture in Africa, the focus has been on livestock and crops and not much attention has being given to the role of wildlife ranching. This is besides evidence suggesting that livestock activities are highly correlated with the performance of wildlife ranching under different climate conditions for instance Kreuter and Workman, (1997) points out that land used for cattle farming are known to be suitable for wildlife. Langholz and Kerley (2006) in a study on the assessment of eco-tourism based private game reserves in South Africa observed that land previously dominated by livestock farming (beef and dairy) and small stock farming (Merino sheep and angora goats) are being converted for wildlife use.

Therefore, what stands out is whether communities or commercial livestock farmers could indeed benefit more by integrating livestock with wildlife or by having different mixed species of livestock or generally changing land use from livestock to wildlife use as a way of adapting to climate change. The prevailing realization is that wildlife ranching comes at a time when in South Africa commercial livestock farming is experiencing a decline at a significantly higher rates. In the previous three census for commercial agriculture for South Africa, there has been noticeable decline in the numbers of commercial farms. For example, the last census on commercial agricultural farms in 2007 noted that there were 39,966 commercial farms, this was a reduction of 12.8 per cent of the number of commercial farming units that were there in 2002 and more than 31.1 per cent reduction when compared to the number of commercial farm units in 1993 (Stats SA, 2002; 2007). On the contrary, the number of farmers currently engaging in wildlife utilization has increased to more than 15,000 with 4000 of them practicing some form of integrated wildlife-livestock land use (Child et al.,2012;Dry, 2010; Langholz and Kerley 2006).

Our study builds on the vast literature on climate change and agriculture especially adaptation to climate change in crops and livestock, (Seo et al., 2008; Erasmus et al., 2002). We extend this literature by considering the role played by wildlife in countries (particularly in Southern African Countries) where private sector-led wildlife utilization has been legalized and as such practiced side by side agriculture. Even though wildlife ranching is assumed to be practiced by rich large-scale commercial farmers in Southern African region, there is indication of emerging small-scale wildlife farmers with an annual turnover far less than R.3 Million[1], StatsSA (2010). At the same time rural communities are also showing increasing interest in wildlife ranching or integrated farming, Chaminuka, (2013).

Therefore, the purpose of this study is to explore the role of wildlife in climate change adaptation in the marginal areas. This is guided by three hypotheses;

1. First we argue that contrary to findings of earlier studies which cited limited adaptation options in marginal areas; wildlife ranching could play an important role in adaptation. The role played by wildlife land use is rapidly growing (Langholz and Kerry 2006: Kreuter and Workman, 1997). It is also estimated that land transition from livestock to wildlife use is growing at a rate of 2-2.5%[2] annually (DEAT, 2005) in South Africa. It then means that ommision of wildlife from earlier studies may have biased results especially those in Southern Africa region.

2. We further argue that determinants of land use change in agriculture strongly correlate with private sector-led wildlife utilization. This implies that factors that derive adaptation choices among farmers in agriculture could as well influence land use decisions on wildlife land use.

3. Finally, the performance of integrated wildlife-livestock farms are likely to outweigh mixed livestock farms. Seo (2010) shows that integrated farms perform better than crop or livestock only farms. However, we extend this literature on resillience of integrated farms by comparing integrated wildlife-livestock farms to integrated livestock farms.

If the government is to recognize the role played by private sector wildlife ranchers and promote small-scale farmers and communities[3] it is important that

[1]Farming units with turnover below R3,000,000 are classified under income groups 3 or 4 while farms with turnover above R3,000,000 are classified as 1 or 2 depending on the cut-off points. Therefore farms with turnover below R3,000,000 could be considered small or medium scale farms depending on the cut off point

[2]This figure has grown to over 5% annually as of 2010 (Dry, 2010).

[3]Some rural communities continue to approach conservation agencies and government for aid to establish small game reserves so that they can also benefit from wildlife production, (Tomlinson et al., 2002) to get involved in wildlife land use.

more information on the performance of integrated wildlife-livestock farms and drivers of land use change is made available. At the moment lack of clear understanding of the linkage between livestock and wildlife in terms of climate change and adaptation in the marginal areas raises the question of whether the current adaptation strategies in these marginal areas fully represent all options available to commercial farmers in such agro-ecological zones. Consequently it also raises the question on whether policies and the management practices currently adopted are for the benefit of both wildlife and livestock. The complexity of wildlife-livestock environment is seen in the lack of synergy and policy lags[4] in wildlife management in South Africa which fall under various government agencies with competing interests, (Child et al.,2012), but with a majority of wildlife ranchers advocating that wildlife ranching should be considered an agricultural activity, (Dry,2012).

The remainder of this paper is organized as follow; in section 2, we review the literature on land use decisions and adaptation in agriculture and wildlife conservation; Section 3 begins with a review of the theoretical framework on land use change, which helps us develop an econometric specification of the model. This is followed by description of the data. Results are presented in section 4 followed by discussions and conclusion in section 5.

2 Literature Review

2.1 Wildlife conservation and Climate Change in South Africa

Wildlife ranching sub-sector in South Africa has grown in magnitude and diversity over the last two decades. According to ABSA (2003), the sub-sector is ranked sixth biggest in the agriculture sector with an annual turnover of over R 7.7.billion as of 2008. The wildlife sub-sector covers more than 20 million (16.8%) hectares of land which is a quarter of 84 million grazing land in South Africa. The sector also holds 2.5 million wildlife which is four time more than those held under the public protected areas (Dry, 2010). Equally, of the total land area in South Africa only 17% is arable with over 87% marginal land.

Over the past decades, the number of commercial farms practicing crop and livestock production have declined by over 31% between 1993 and 2007. One of the biggest challenge has been associated with climate change since much of the production activities in agriculture has been rain-based yet South Africa is one of the most water stressed countries in Africa. Livestock production is facing an uncertain future in South Africa. Seo and Mendelsohn (2008) find that with a warming of $+2.5^0$C over the current climate the areas for beef production in South Africa will shrink dramatically and almost entirely disappear with over $+5^0$C temperature increases over the current level.

[4] Currently Department of Agriculture in Limpopo Provincial Government is in the process of formulating a Game Farming Strategy. This could implies that until recently wildlife ranching has been operating in a policy vacuum.

The effects of climate change have also extended to biodiversity conservation especially wildlife conservation in the public protected areas. One would obviously expect the effects of climate change to extend as well to wildlife conservation in the private sector. But there is need to link wildlife utilization to livestock production in the marginal areas as an opportunity for wildlife conservation as well as food production.

Closely related to the discussion above is the literature on land use change which talks of determinants of land use conversion or change. In order for us to evaluate the role played by wildlife in adaptation, it is important to understand how different the environment livestock and wildlife farmers operate in in terms of land utilization. Livestock farmers are known to use financial capabilities to overcome the effects of climate change in the short run. However, in some cases, farmers have changed the composition of their stock by moving away from larger stock to small stocks which are perceived to be more tolerant to climate factors. Some farmers have on the other hand practiced mixed livestock farming where small stock have been mixed with larger stock. It is therefore necessary that we first investigate if the factors that influence change of land use within the livestock sub-sector could also play a role in changing land use from livestock to wildlife.

In literature, several factors are known to influence land use change decisions and adaptation in agriculture. These factors may include; biophysical factors (sometimes referred to as ecological factors) such as soil and climate type which can limit the type of crop or livestock that a farmer can have on his field hence reducing the ability of a farmer to adopt some strategies, (Kurukulasuriya et al., 2008). Most common types of soil in the marginal areas of South Africa are largely composed of arenosols, fluvisols, ferralsols, lixisols, leptosols, durisols and luvisols among others. Areas considered favourable for livestock production are known to have relatively poor soils, erratic rains or generally marginal, (Rubel, and Kottek, 2010). Agro-ecologists use land evaluation techniques to determine the potential land uses for a location based on the biophysical characteristics of the location (Fischer et al., 2002).

Other factors considered relevant in land use change are economic factors for example farmers' access to capital or assets that is known to influence the ability of farmers to adapt to climate change. Financial capabilities means that farmers are able to invest in new technology, (Cooper et al., 2009). Farmers with finances are therefore able to move to alternative land use such as wildlife because they are in a position to invest in capital assets. Farmers with diverse sources of income may be more able to adapt because they mitigate the risks of climate change by earning income from different sources, (Adger et al., 2009). Other studies have suggested that farms with larger parcels of land are also likely to adopt new strategies, (Erenstein and Laxmi, 2008). Finally social factors for example farmers who have strong social networks are more likely to try alternative farming activities due to social pressure which is backed by strategic information on both biophysical and business related issues, (Matuschke and Qaim, 2009).

Besides the general consensus that the perception of farmers about climate change often influence their response to land use and adaptive decision in a shifting climate, (Wiid and Ziervogel,2012) other known factors that drive adaptation choices among farmers in agriculture are internal and relates to farmers' managerial preferences, entrepreneurial drive or peer opinion, (Bryant et al., 2000; Smit and Wandel, 2006). They can also relate to external factors such as regional dynamics, political and cultural institutions, social networks and availability of resources, (Adger et al., 2003; Adger et al., 2012). But what underlines these choices in a climate impacted environment is that farmers' response to climate change is in part influenced by their perception about climate variability, (Wiid and Ziervogel, 2012; Bryant et al., 2000). Farmers who have transited from livestock to wildlife may be better placed to provide knowledge on both non-climate and climate related factors which could motivate adaptation responses including land use change. The economic and agronomic estimated results of recent studies on climate change and livestock in South Africa may be confounded by the large presence of wildlife ranches which has not been considered in these studies. Therefore the current debate may turn out to paint a false picture on the available adaptation options for commercial and small-scale farmers in these regions. For example, in a climate-impacted scenario, available adaptation option for large-scale beef farmers may be in sheep rearing, (Seo et al., 2008), if however beef farmers reallocate to wildlife ranching, it is likely that the current estimates based on Ricardian approach for beef in the Southern African region is biased.

In South Africa, studies on climate change and livestock show worrying results given that farmers experiencing water challenges may reach their financial adaptive limits in livestock if climate change remains severe, (Bomhard et al., 2005). Earlier predictions by Seo and Mendelsohn, (2008a) indicates that a +2. 5^0 C to + 5^0 C temperature increase over the current levels is likely to wipe out cattle or beef farms and shrink drastically sheep farms in Southern Africa region.

Farmers who are vulnerable to climate change have undertaken various adjustments to able to adapt For example small and large scale farmers have moved production from one form of cropping to more drought resistant varieties or shifted from cattle or beef production to sheep farming in dry areas or goats and chickens in wet areas, (Seo and Mendelsohn, 2008a); in other areas in Africa, farmers have tried joint production of crop and livestock or moved to forestry, (Seo, 2010a); there are also cases where farmers have moved from crop production to livestock production or mixing different species of livestock, (Kabubo-Mariara, 2009). But not much has been done to evaluate performance of those farmers who have chosen wildlife land use as alternative way of adapting.

In South Africa, even with these adaptation options the number of commercial farms continue to drop. On the contrary, the number of commercial farms engaged in wildlife ranching activities has increased at a rate of 5 per cent annually, (Dry, 2010). This is partly attributed to profitability of wildlife ranching over livestock, (Langholz et al., 2006).

As Vedwan and Rhoades (2001) observed, farmers are best placed to know how climate fluctuations impact on farming practices. But farmers may underestimate their ability to respond because of how they perceive environmental risks in terms of personal control over global and regional external environment stresses, (Gardner and Stern, 1996).

Wildlife utilization on private land comes at a time when an important ongoing debate is about how agriculture and biodiversity should be integrated, (Green et al., 2005). In this emerging literature, the discussion is on whether agricultural policies should encourage land sparing or wildlife-friendly farming, (Fischer et al.,2008). Wildlife friendly farming assumes that human activities and nature can coexist in socio-ecological system, (Berkes, 2004) and that interactions between nature and agriculture are of great interest, (Tscharntke et al., 2012).

The importance of wildlife ranching as a better alternative to ex-situ conservation is emphasized in the latest IPCC Fifth Assessment Report (AR5). Von Maltitz et al., (2006) also observes that conservation through expansion of public reserves in the face of climate change will be more expensive, while ex-situ option could be considered as the last option. What would be more cost-effective would be contractual reserves (Matrix management) on private land. This is because the range-land management is already biodiversity-friendly for many species. It is consider potentially cheaper because the economic incentives have already led landowners in these areas to use their land for non-agricultural activities such as ecotourism and wildlife ranching since they provide better returns.

Of particular interest however is the role of incorporating wildlife ranching practices in livestock production as a means of climate change adaptation. Kreuter and Workman (1997) explored the impact of integrating cattle with wildlife ranching and Child et al., (2012) looked at the economics of private sector wildlife conservation. In both case, these two studies did not exclusively model adaptation in wildlife ranching. Many studies consider change in farming behavior such as switching species of livestock as adaptive,but it is important to consider the outcome of such behavior to understand how well farmers are able to adapt to changes in climate. By considering the outcome of the decision making, it is possible that certain coping strategies could be shown to be non-beneficial or maladaptive, (Barnett and O'Neill, 2010).

3 Research Methods

3.1 The theory

Farmers are expected to optimize their well-being by allocating or converting land to alternative uses that maximize their utility. Therefore a profit maximization model is adopted in this study. A farmer chooses a type or combination of farming practice which generates the highest profits. Profit maximization models have been used in literature to explore optimal farm plans, (Van Ittersum et al., 1998). In agriculture, especially small-scale or subsistence farming, profit maximization models are criticized on the basis that the assumption that farmers maximize profits may not necessarily be true, (Rufino et al., 2010; Barnett and O'Neill, 2011). Commercial ranching is however based on the assumption that a farmer's main objective is to maximize profit and therefore land use management happens in pursuit of profits besides other possible objectives. The preference of a given land use option is assumed to be influenced by a set of factors such biophyscial, economic or social. We look at landowner's problem in a climate-impacted scenario to involve decision on either to continue with livestock ranching or transit to wildlife ranching.

A profit maximizing landowner with a parcel of land of size S with multiple uses which can include livestock and wildlife denoted by l and w respectively at all points in time such that $l_i + w_i = S_l$. Therefore the landowner has to choose at each point in time how much of land is put to either uses to maximize the present discounted value of benefits less the cost of conversion. That is;

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

$$\begin{aligned} & s.t \\ \dot{S}_l &= (a_{wl} - a_{lw}) \end{aligned} \tag{2}$$

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

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

(Note: biophyiscal factors such as precipitation, soil and temperature variations are allowed to influence conversion costs)

Where;

L and W; are livestock and wildlife land use respectively.

S_l - Stock of land on use l

a_{lw} – number of ha of land converted from use l to w at point in time.

R_w – Net benefits from an ha of land in use W

$C_{lw}(a)$ - The total cost of converting an ha of land from use L to W.

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 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 w is optimal if the expected present discounted value of an infinite stream of net returns to use w less conversion cost is greater than the present discounted value of net returns from use l. That means that the farmer chooses the use with the highest return which maximizes her utility.

3.2 Empirical strategy

This study is motivated by three questions. i) What are the drivers of land use change in the marginal areas? ii) How vulnerable are wildlife ranches when compared to livestock ranches? iii) What role will wildlife ranching play in a climate impacted scenario? In order to address these questions, in the first stage, we have divided our sample into two categories; livestock farmers and wildlife farmers.

From the previous theoretical formulation, a landowner with a stock of land and facing land use choices of either livestock or wildlife has a profit function;

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

Using the general random utility expression we can represent the expected profit when landowner moves from a given land use allocation for example livestock to wildlife as;

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

Where V_{ilw} is a vector of observed variables, β_i is the parameters and ε_{ilw} is the random error term.

Our first interest is in the probability of land use change at certain locations relatives to all options. The hypothesis was that the factors that drive land use choices within the livestock sector could as well drive land use decisions from livestock to wildlife. Therefore a dichotomous specification of the regression is chosen. The statistical model developed is a discrete probit model of two choices; convert location i into wildlife use or not. Clearly the preference for the location cannot be observed, therefore analysis of this dependent variable requires a binary response model. 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 and ε is the error term and $1[y* > 0]$ which defines the boundary outcome. The error term is assumed to have a standard normal distribution characteristic of a probit model, (Cameron and Trivedi, 2010). A probit model is preferred because given the normality assumption; several specification problems are more easily analyzed, (Baum, 2006).

Having determined that factors responsible for land use choices in livestock sector could as well determine choices of land use in the wildlife-livestock sphere, we now compare the choice of farming system that includes wildlife and integrated wildlife-livestock farms to those that only practice livestock farming. The outcome of the choice a farmer makes is assume to be one that has the highest net revenue. Therefore, conditional on the type of farming choice made, we are able to estimate the net revenue of the farm chosen.

The basic model is given by;

$$Y_1 = X_1\beta_i + \varepsilon_1 \tag{10}$$

$$Y_s^* = Z_s\gamma_s + \eta_s \tag{11}$$

Where Y_1 refers to the net revenue per ha associated with specific farming choice (livestock, wildlife or mixed wildlife-livestock). Y_s^*, is a discrete choice variable indicating the categories of different farm choices. X_1 and Z_s are explanatory variables that include biophysical factors, economic and social factors. ε_1 is the disturbance term that satisfies the normal assumptions $\mathrm{E}(\varepsilon_1/X) = 0$ and $\mathrm{V}(\varepsilon_1/X, Z) = \sigma^2$.When we use the normal OLS to estimate the revenue equation, each revenue equation is run separately. But there are problems of unobserved characteristics which affect both the choice of the ranching type and the revenues generated which implies that the error terms ε_1 and η_s will be correlated and the estimated β_i will be inconsistent. In order to correct for such inconsistency, bias correction methods such as Heckman, (1979) two-stage selection model to the multinomial case is used. We follow (Dubin and Rivers, 1989; Dubin and McFadden 1984), for the selection bias correction in the multinomial which is extended by Bourguignon et al., (2007) who offer an alternative approach which take into consideration the correlation between the disturbance term from each of the revenue equation and the disturbance term from each of the multinomial logit equation. In their model they assume a linear association between ε_1 and $\eta_s, \varepsilon_1 = \sigma_i \sum \rho_s \eta_s * + \omega_i$. The residual term is orthogonal to all $\eta_s *$: The bias corrected net-revenue equation becomes;

$$Y_1 = X_1\beta_i + \sigma_1 \left[\rho_1 m(P_1) + \sum \rho_s \frac{P_s}{(P_s - 1)} + m(P_s)\right] + v_1 \tag{12}$$

Where P_s is the probability that a category s is chosen and $v_1 = \eta_1 +$ log P_1. Estimates of σ_1 in the above equation are consistent. The second term on the right equation corrects for the selection bias. In this study, this term explains the interactions between livestock, mixed wildlife-livestock farms or wildlife only farms. The number of bias correction terms in the equation is equal to the number of multinomial logit choices. The Bourguignon et al., (2007) 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 model is further preferred because of its flexibility incase non-linear specification are present and the independence of irrelevant alternatives (IIA) is violated, Dimova and Gang (2007).

3.3 Data

This study combines three different datasets; first a sample of wildlife and livestock farms is drawn from latest commercial census of agriculture for South

Africa (StatsSA 2010) data carried out in 2007. While the census was conducted for the nine provinces in South Africa, we are only able to use data from six of the nine provinces. These provinces have over 80 per cent of the wildlife ranching activities in South Africa. Farm level data allows us to categorize farms into integrated wildlife-livestock ranches, wildlife only ranches and livestock ranches. Therefore, a sample of 1071 farms has been drawn as follow; 355(33%) of farms practice livestock farming; 495(46%) practice mixed wildlife-livlaestock farming while 221(21%) practice wildlife ranching. Data on climate[5] variables is obtained from Climate System Analysis Group. Soil data for the districts have been obtained from the Food and Agriculture Organization. Both climate and soil variables have been clustered at the district municipality level using the geographical information systems.

The dependent variables will include the discrete and mutually exclusive categories of ranches and the net farm revenues from wildlife and livestock ranching. We have three sets of independent variables; first is the biophysical variables which includes temperature, precipitation and soil variables; second is the economic variables which are represented by access to assets[6], land size and farm turnover and lastly social factors which is represented by social networking through memberships and affiliations to relevant groups. We have also control for regional fixed effects.

3.3.1 Descriptive Statistics

Table 2 provides an overview of the descriptive statistics of the key variables of the study. In the three categories, livestock ranches represent those ranches which have a combination of larger animals (Cattle) and smaller animals (Sheep and goat). Therefore, the sample of livestock farms used is that of farmers who practice mixed livestock species farming. On the other hand, mixed wildlife-livestock ranches represent ranchers who have both large and small animals in addition to wildlife. These farmers are different from the category of livestock farmers simply because they keep wildlife over and above livestock. The final category is that of wildlife ranches, these are ranches which only have wildlife on them.

It can be seen from a comparison of the three categories that net revenue from livestock and mixed ranches are on average higher than those from wildlife ranches. This seems counterintuitive given that it is known that revenues per hectare of land used by wildlife is higher, (Dry, 2010; Kreuter and Workman 1997), however, over 88 per cent of farms in our sample are classified under income category 3 or 4. This implies that they are mostly small scale when compared to some larger mixed ranches or livestock only ranches[7].

[5] The mean temperature and precipitation for over a period of 30 years

[6] There are farms that had infrastructure on them especially cattle sheds that were later modified into accommodation for ecotourism, other farms had office spaces used for cattle management that were also converted. The asset variable is a discrete variable, which captures those farms with such infrastructure on them.

[7] A small game ranch with economic carrying capacity has an equivalent of 150 Large Stock Unit (LSU), ABSA(2003).

It comes as no surprise that land sizes of wildlife ranches are smaller when compared to mixed and livestock ranches. As earlier explained, the livestock category used in this study is composed of livestock farmers who practice mixed livestock ranching. Therefore we expect that both livestock and mixed ranchers are relatively bigger than wildlife only ranches. However a higher number of mixed ranches and wildlife ranches have high turnover at 6 per cent and 3.5 per cent respectively when compared to livestock ranches at 2.9 per cent.

Access to water is one of the most important input on a ranch given that South Africa is water stressed. Around 13 per cent of livestock ranchers depend on water they purchase compared to 12 per cent and 8 per cent for mixed ranchers and specialized wildlife ranchers respectively. Most ranchers however depend on altenative sources of water such as stream flow, boreholes among others.

Another important determinant of land use conversion or change is social factors. We proxy for farmers relationship with social networking. Both livestock and wildlife farmers join or are affiliated to social networks for several reasons. What is most important is that farmers' actions are sometimes influenced by these membership organizations. Social networks provide an important avenue for information and bargaining power, therefore ranches join different bodies for some of these reasons. The difference in enrollment in these bodies among both livestock and wildlife is diverse. Around 50 per cent and 42 per cent of livestock and wildlife ranches respectively are in networks. In contrast, up to 62 per cent of mixed ranches are affiliated to these network.

In table 3, the climate variables (average monthly temperature and rainfall) are presented for summer and winter. Monthly rainfall has been measured in millimeters, while temperature has been measured in degree Celsius. Only mean rainfall is presented for the two seasons. However, temperature has been captured for the minimum, mean and maximum temperatures. In terms of location of ranches based on climatic conditions, most wildlife ranches are located in areas which are comparatively hotter in both summer and winter when compared to livestock and mixed ranches. On average temperatures in these areas are above 22.6^0C and can go as high as over 29.2^0C on average. A comparison of the three systems in terms of climate variable suggests that location of wildlife ranches are highly correlated with climate conditions. There is however not much difference in precipitation during summer, though areas predominantly occupied by wildlife seems to be those with less winter rains.

While ranches are found across the entire regions of South Africa, a significantly higher number of wildlife ranches are locate in areas where the dominant soil type is characterized by leptosols and lixisols. Mixed ranches are in areas where soil is characterised by leptosols and durisols, livestock are also in areas with large amount of lixisols and leptosols. According to FAO, (2014) Lixisols are under savannah or open woodland vegetation. Such area are often used for low volume grazing. Leptosols soil is unattractive soil for arable cropping withlimited potential for tree crop production or extensive grazing. Durisols can only be used for extensive grazing. Finally Luvisols with a good internal drainage are potentially suitable for a wide range of agricultural uses because of their moderate stage of weathering and high base saturation. Much of the Leptosols and Lixisols are found in Limpopo province. Some part of Eastern Cape province have arenosols, plenty of leptosols and luvisols. Northern Cape has lixisols and aerosols while in some parts of Mpumalanga province we find leptosols.

We carried out a one-way analysis of variance (ANOVA) to see whether the means of variables used are different in the three independent categories of ranching. Taking the case of net revenue per ha, we establish that there was a statistically significant difference between groups as determined by one-way ANOVA (F (20.05), p = 0.000). A Tukey post-hoc test revealed that net revenue per ha were higher statistically in the three categories. We obtain the similar results for land size and asset availability.

Though the ANOVA test for asset variable was statistically significant, a Tukey post-hoc test revealed that the difference in means was not statistically different between specialized wildlife ranches and livestock Ranches. The test confirms that the source of significance was due to differences in mixed ranches and specialized ranches. Equally, the test reveals that the means difference in purchase of water, is not significant.

4 Empirical Results

The results of the binary probit model used to evaluate determinants of land use change is reported in table 5. These factors were classified as biophysical (for example the type of soil and climatic conditions faced by the ranchers); economic factors (includes asset; this is the value of investment in physical assets, Land size and farm turnover); Social factors (this includes social networks for example membership or affiliations to associations proxied for by payment of membership fees). We also control for regional dummies.

We earlier showed that wildlife and livestock ranching are carried out in areas where soil are generally poor and the temperatures are comparatively high with equally lower rainfalls. In our probit results, we see that leptosols has a positive coefficient. Soils characterized by Leptosols is known to be unattractive for cropping and extensive grazing, (FAO, 2014). It implies therefore that areas predominantly characterized with Leptosols have increased probability of practicing wildlife ranching. Such soils decrease crop use, (Seo, 2010b). For the case of climate conditions, the probability of a livestock rancher changing land use increases rapidly with increasing temperatures. The non-linear term is hill-shaped which means that the probability of changing land-use increases rapidly with increasing temperatures since climate has a damaging effect on livestock production. We also see that as annual rains increase, livestock ranchers would prefer to change land use to wildlife ranching.

The size land of available to a farmer and access to capital assets such as investment in buildings are known to influence the decisions of a ranchers on land use. We looked at two of these variables considered in literature to influence land use change. The size of land is known to motivate private landowners into considering a number of conservation behavior, Lambert et al., 2007). The probit results shows that the size of land increases the probability of a livestock rancher moving to wildlife farming. However, we also see that livestock farms with higher turnovers are less likely to change from livestock to wildlife ranching. This could indicate that one of the reasons why farms change land use is because of lower returns or productivity of livestock production. Ranches which had assets have a higher probability of moving to wildlife ranching. Cases of the ranches transforming old farm houses into lodges for ecotourism in South Africa have been reported.

Social networking is proxied for by membership or affiliation to a body dealing with livestock or wildlife activities. This is a case where a rancher is a member of some form of association. The role of social networking is very important to land use decision making since one being in a social network increases access to production information, market support or collective bargaining power. The use of land and trend in land use in the neighbourhood plays a role in influencing land use change. Our result show that association with these bodies increase the probability of a rancher moving to wildlife ranching, this is consistent with earlier narratives in literature.

We also controlled for regional dummies. Northern Cape Province was the reference province. The study reveals that holding other factors constant in the current climate scenario, ranches in Limpopo and Eastern Cape are more likely to prefer wildlife to livestock when compared to Northern Cape Province. Eastern Cape Province has the highest number of cattle, sheep and goat farms contributing over 24 per cent, 29 per cent and 38 per cent of total national cattle, sheep and goat population, (DAFF,2014). Limpopo Province has half the total population of wildlife ranches and wild animals outside the protected areas. Individual farms in Free State and North West are less likely to prefer wildlife ranching when compared to Northern Cape province. This is expected because the two provinces (North West and Free State) are largely arable with Free State contributing 32 per cent of total arable land followed by North West province with 17 per cent of the total arable land in South Africa, Benhin, 2008). In areas such as Eastern Cape which generally receive poor rains and farmers are more commercial oriented with 14 per cent of them undertaking commercial livestock farming (13 per cent of all commercial farmers come from Eastern Cape province), they are likely to move to wildlife farming. Current climate makes ranchers in Limpopo to be almost twice more likely to move to wildlife ranching when compared to ranchers in a province such as Eastern Cape.

The role of wildlife in adaptation: a Multinomial logit approach

There is potential land use change in future because of climate change and this will change the way farmers utilize their land, (Seo 2010a). We empirically explored whether wildlife related ranches are less vulnerable to climate change when compared to livestock ranches. This can also be compared to the narrative in the literature which postulates that wildlife is more resilient to weather variability and as such wildlife revenues perform better when compared to livestock in the marginal areas.

We progressed with the analysis in two stages; in the first stage, we use a multinomial logit to model determinants of ranching choice. This step not only provide an insight into the determinants of choice of ranching systems under the three options of ranching, but also generates selection bias correction terms for the second stage where we evaluate the conditional revenue equation for the type of ranch chosen after correcting for the selection bias using the, (Bourguignon et al., 2007) approach. Previous challenges associated with identification of adaptation responses are known to be proned to omitted viable bias (Wang et al., 2014).

Diagnostic Tests

We begin with diagnostic tests to establish if the choice of the model of analysis best suits the research question.

Wald test for independent variables

Most of our variables are significant at between 1% and 5%. For the two soil variables which are not statistically significant, but potentially important in our model, we carry out a further test using joint Wald test to see whether the two variables are statistically significant as a set so that we can see if it makes sense to retain them. Looking at the Wald test results for the set 1 (table 6) we find that even as a set, the two variables are still not significant and can therefore be dropped from the model.

Test for whether the categories of the dependent variables can be combined

We also tested whether it may have be necessary to combine some categories; we can combine them if our dependent variables jointly do not differentiate between the two categories (meaning that nothing predicts that they are different).

Our test results in table 7 reveals that the categories are independent and cannot therefore be collapsed.

Test for Independence of Irrelevant Alternatives (IIA)

Even though our choice of model allows us to estimate our conditional net revenue even when the IIA is violated, (Bourguignon, et al., 2007; Dimova, R. and Gang, 2007), we nonetheless tested for IIA using the Small-Hsiao approach. The results are outlined in table 8

The results imply that the IIA is not violated; the odds for each specific pair of outcome does not depend on other outcomes available. We have not carried out a suest-based Hausman test though we are aware Hausman and Small-Hsiao tests may give inconclusive or sometimes contradictory results, (Long and Freese, 2006). However, as indicated earlier, the use of, Bourguignon, et al., (2007) allows for our choice of model because whether IIA hold or not does not affect the results as indicated in the discussion about the model. The results of multinomial logit choice model are therefore presented in table 9.

5 Discussions of the results

As earlier indicated, there are several variables that influence choice of a ranching system; these factors included biophysical, economic and social factors. We estimated the probability of a farmer choosing one of the three available ranching options given the current climate conditions. The reference category was livestock ranching. From the results, we see that the odds of selecting mixed ranches increase with the farm turnovers, farms with larger turnovers are 2.067 odds of choosing mixed ranches when compared to livestock ranches. Equally important is assets, we see that farms with assets are 58 per cent more likely to choose mixed ranching as opposed to livestock ranches.

Looking at the role of temperature and precipitation in the selection of farming option, temperature for example increases the probability of a farmer choosing either mixed ranches or specialized wildlife ranches. In the linear term of temperature, the odds ratio initially shows that the odds of choosing specialized wildlife farms reduce by 99 per cent, but the quadratic term shows that the odds reduce but after the turning point, they are eventually positive (15.8 per cent odds of choosing wildlife over livestock). On the contrary, the odds of the linear term for precipitation suggests that the probability of choosing either specialized wildlife or mixed ranches increases by 37.9 per cent and 21.4 per cent respectively. However, the quadratic term suggest that this probability increases at a decreasing rate and eventually the probability of choosing either mixed ranching or specialized wildlife ranching reduce by 0.01 per cent in both cases. It can also be noted that the probability of selecting wildlife farming decreases in cases where durasols is the most common soil type while the probability of choosing wildlife ranching increases where soil is more characterized with lixisols.

5.1 Vulnerability of various Ranching systems

One of our empirical questions was which of the three ranching systems was more vulnerable to climate change. The vulnerability of each of the three ranching categories can be determined by calculating the change in the marginal effect on the probability of choosing a specific system of ranching when climate variable is perturbed by a small change in temperature or precipitation, (Seo, 2010a). We calculate the probability of choosing each approach if the system is perturb by 1^0C increase in temperature and a 1% decrease in precipitation, the results are presented in table 10. A 1^0C increase in temperature over the current levels will increase the probability of choosing either specialized wildlife ranching or mixed wildlife ranching but significantly reducing the probability of choosing livestock ranching. It can also be noted that the choice of mixed ranching will be higher than those of specialized ranching. Equally, the probability of choosing specialized wildlife ranching or mixed ranching is likely to increase if precipitation reduce by 1% over the current rates. However, in the case of livestock choice, the probability of choosing livestock is likely to decrease with decrease in precipitation.

5.2 Conditional Net Revenue estimation

The question which follows then is which of the three systems yields more revenues given that it is choosen. If a rancher has chosen one of the three ranching options, the rancher seeks to maximize net revenues by choosing appropriate level of inputs and outputs. After accounting for selection bias of individual farmers into the three categories, we can estimate the conditional revenue equation for each option. The selection bias coefficient represented by M0-M2 are the BFG equivalents for the Mill's ratio. The terms show the interactions among the three systems of ranching discussed. In table 11, we present the results of the conditional net revenue estimation. The results indicate that the net revenues of livestock ranches are sensitive to both summer and winter temperatures as indicated by the hill-shape relationship between the net revenues and temperature variables. However, an increase in winter precipitation seems to be beneficial to revenues of livestock farmers. Revenues of mixed ranches perform better in areas where the soils are predominantly durisols or lixisols while revenues of livestock perform better in areas which have lixisols.

We note that the selection bias correction coefficient of specialized wildlife farms are positive and significant in the choice of both mixed ranching and livestock ranching. Essentially this shows interaction between these farms. More specifically, it implies that holding other factors constant, on average mixed ranches and livestock ranches are more likely to make more profits if they were to choose specialized wildlife ranching. On the contrary, if ranchers currently practicing specialized wildlife ranching were to choose either mixed ranching or livestock ranching, then the negative selection bias correction term suggests lower profits than the current levels. Mixed ranches are also likely to make lower profits by choosing livestock ranching under the current climate conditions.

The conditional net revenue analysis results support the multinomial choice results. Even though mixed ranches are less vulnerable with a small peturbation when compared to specialized wildlife ranching, the conditional net revenue results suggest that specialized wildlife ranches are likely to be more profitable in the current climate scenario when compared to mixed ranches.

5.3 Future land use change in the marginal areas

The distribution and choice of farming systems across South Africa as a consequence of climate change is likely to adjust more so in the marginal areas. So far the adaptive changes made by crops and livestock farmers reflect these adjustments to climate change given the prevailing climatic conditions. However, recognizing that livestock ranchers in the marginal areas may consider wildlife if the current climate were to change as predicted by various models, there would be further adjustments in which more farmers currently practising livestock or mixed farming would consider wildlife use. In this section, the probability of change in land use is measured using different climate scenarios. This is done by taking the difference in the probability of choosing land use before and after climate change for each climate scenario. Projections with Climate Scenarios uses three Atmospheric-Oceanic Global Circulation (AOGCM) climate scenarios. This includes CSIRO2, Parallel Circulation Model (PCM) and Hadley Centre Coupled (HadCM3) model which have been used in literature for South African, (Benhin, 2008). The predicted change in choice of land use as temperature and precipitation for South Africa change is as follows;

As can be seen across different models, as climate warms, there will be significant adjustments across farms especially livestock farms. All the three AOGCMs predict that the probability of livestock ranches moving will increase substantially by up to 74 per cent in some cases. By 2050, livestock farmers are likely to move away from livestock ranching into wildlife ranching. The reduction in precipitation is also likely to influence the probability of livestock ranchers moving to wildlife ranching. We have also looked at the probability of livestock ranchers moving to mixed ranching as climate changes. The probability of livestock ranchers moving to mixed ranchers increases with warming. The increment in probability to move is however not as high with rainfall. It appears that in the medium term, livestock and mixed ranches may use financial solutions to temporary cope with climate change instead of moving to alternative land use, but eventually moving may turn out to be an alternative option under future climate.

In the following section we have examined land use change across three regions known in South Africa to have the highest number of wildlife ranches (Limpopo Province) and those known to have the highest number of commercial livestock farms (Eastern Cape Province). The objective is to see how farmers in these provinces are likely to respond to climate change in terms of wildlife to livestock land use choices.

Regional climate interactive term suggests that warming will increase the probability of ranches moving to specialized ranching. Temperature will increase the probability of both mixed ranches and livestock ranches moving to wildlife ranching. For example in Eastern Cape province, the probability of livestock ranches moving to wildlife ranching increases by 28% according to HadCM3 by 2100. What we also notice is that the probability increases marginally with precipitation. In the medium term, ranches in Eastern Cape and Northern Cape are more likely to move to wildlife ranching than those in Limpopo Province. Even though one would expect most changes to be in Limpopo, this is not the case because a high number of farms in Limpopo are already practicing wildlife ranching.

6 Conclusion

Climate change will continue to threaten conservation and agriculture especially commercial livestock farming. In this paper, we set out to first establish if factors responsible for land use conversion or change in crops and livestock could play a role in land use conversion to wildlife ranching. This is because livestock and wildlife activities are known to be corelated in the marginal areas. We then moved on to evaluate how vulnerable wildlife ranches were to climate change when compared to alternative land use especially livestock farms. Finally we looked at current land and future land use trend to determine what contribution wildlife ranches would make in a changing climate. Overtime farmers have changed land use from livestock ranching to wildlife mainly due to climatic and non-climate factors. The land use changes being observed among farmers and which the data has been able to corroborate confirms that factors responsible for land use change in other agricultural sectors could as well influence land use change to wildlife ranching. In essense this means that wildlife ranching can be considered as an alternative adaptation option.

While wildlife ranching has not been subject to agriculture and climate change studies as yet, the results of this study lend themselves for a comparison with earlier findings by Seo and Mendelsohn, (2008a). Using South African beef cattle, they find that with warming of $+2.5^0$C over the current climate, the areas for beef cattle will shrink dramatically and almost entirely disapear with warming of over $+ 5^0$C . There will also be widespread reduction of sheep in South Africa. We show that with a warming of around $+9.6^0$C, the probability of livestock farms moving to wildlife ranching would have increased by 74%. Even though (Seo, 2010a) finds integrated crop and livestock farms to be more resillient to climate change, we find that integrated livestock-wildlife ranches are less vulnerable to climate change when compared to integrated livestock only farms.

The question is whether institutional framework of managing agriculture sector is growing at the same pace wildlife ranching sector is growing. The model has predicted that the probability of more farmers moving into wildlife conservation in the marginal areas is going to increase as the temperatures warm up. Areas such as Eastern Cape Province has the highest number of livestock farms and plays a very important role in food security in terms of beef production. However, it is also in this area where the greatest adjustment is likely to take place as beef cattle farmers move to alternative land use. Therefore there is need to focus attention on sustainable growth of both wildlife and livestock in the marginal areas. This is because a number of farmers may not be resource endowed, but willing to move land to alternative use either through established empowerment programmes or sell off land to resource endowed commercial farmers who could use such land for wildlife farming.

While previous studies have predicted that large livestock farms will be hurt most by warming, the analysis reveal that wildlife land use will provide an alternative option for land use. Linking wildlife and agriculture provides a sustainable land use option in the marginal areas which would be good for conservation. All the AOGM model predict that land use change will accelerate. Temperature will have a significant damaging effect increasing the probability of land use change. Livestock ranches would be the most affected and they would have the highest probability to switch. Most land use change will occur in Eastern and Northern Cape region.

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Table 2: Descriptive Statistics for wildlife and livestock ranches

Variable	**Livestock Ranching**		**Mixed Wildlife and Livestock**		**Wildlife Ranching**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Log Net Revenue/ha	12.84	1.29	12.68	1.49	11.84	1.66
Land Size	8961.93	71222	6438.22	35043.33	2838.25	9620.1
log of Land size	7.8	1.12	7.64	1.26	6.59	1.57
Water Purchase	0.131	0.34	0.12	0.33	0.08	0.27
Assets	0.77	0.42	0.84	0.36	0.74	0.44
Membership	0.51	0.50	0.62	0.49	0.42	0.49
Farm turnover	0.029	0.17	0.06	0.23	0.035	0.18
Soil: Fluvisols	0.30	0.46	0.56	0.5	0.43	0.49
Soil: Ferralsols	0.26	0.44	0.26	0.44	0.55	0.5
Soil: Lixisols	0.81	0.39	0.75	0.43	0.93	0.25
Soil: Arenosols	0.53	0.50	0.49	0.50	0.66	0.47
Soil: Luvisols	0.62	0.49	0.72	0.45	0.44	0.5
Soil: Leptosols	0.78	0.41	0.95	0.20	0.93	0.24
Soil: Durisols	0.65	0.48	0.81	0.39	0.70	0.46
Observations	**355 (33%)**		**495(46%)**		**221(21%)**	

Table 3: Climate Variables

	Wildlife ranches			**Mixed Ranches**			**Livestock ranches**		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
Summer Temperature	15.9	22.6	29.2	13.8	21	28.3	13.9	21.1	28.31
Winter Temperature	4.9	13.3	21.7	3.5	11.4	19.4	2.7	10.9	19.3
Summer Rainfall (mm/month)	-	84.8	-	-	74	-	-	78.6	-
Winter Rainfall (mm/month)	-	36.5	-	-	41.9	-	-	41.7	-

Note: Temperature is measured in ^{0}C while rainfall is measured in mm /month

Table 5: Predicted Probability of Land Use Change

VARIABLES	Predicted prob.	Std. Err.
Land size	0.056***	0.020
Assets (Not including land).	0.254***	0.050
Membership/Affiliation	0.254***	0.044
Annual Temperature	0.969***	0.242
Annual Temperature sq.	-0.017***	0.005
Annual Precipitation	0.043***	0.011
Annual Precipitation sq	0.001***	0.0001
Farm turnover	-0.314***	0.105
Soil: Arenosols	0.039	0.063
Soil: Luvisols	-0.221***	0.061
Soil: Leptosols	0.400***	0.086
Eastern Cape	0.329***	0.096
Free State	-0.401***	0.099
Limpopo	0.666***	0.130
Mpumalanga	0.006	0.134
North West	-0.409***	0.104
Constant	-16.63***	2.973
Observations	1071	

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. All predictors at their mean value and Northern Cape is the reference province

Table 6: Wald test for independent Variable

Variable	Chi2	D.f 2	P>chi
log of Land Size	86.2	2	0.000
Membership	59.40	2	0.000
Assets (excluding land)	6.248	2	0.044
Annual Temperature	22.9	2	0.000
Annual Temperature squared	25.46	2	0.000
Annual Rainfall	42.92	2	0.000
Annual Rainfall Squared	15.68	2	0.000
Soil: Fluvisols	14.42	2	0.001
Soil: Lixisols	33.92	2	0.000
Soil: Arenosols	1.85	2	0.396
Soil: Luvisols	5.23	2	0.073
Soil: Leptosols	2.32	2	0.314
Soil: Durisols	7.29	2	0.026
constant	17.97	2	0.000
Set 1	4.42	4	0.351

Note: HO: All coefficients associated with given variable (s) are zero.

Table 7: Test on whether the categories of the dependent variables can be combined

Categories tested	chi2	D.f.	P>chi2
Wildlife-Mixed wildlife-livestock	195.897	14	0.000
Wildlife only-Livestock only	280.220	14	0.000
Mixed Wildlife&livestock -Livestock	148.165	14	0.000

Note: Ho: All coefficients except intercepts associated with given pair of outcomes are 0 (i.e., categories can be collapsed).

Table 8: Test for independence of irrelevant alternatives

Ranch Type	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Wildlife only Cons.	-0.578	0.070	-8.25	0.000	-0.716	-0.441
Livestock Cons.	-0.435	0.069	-6.49	0.000	-0.566	-0.304

Note: Mixed Wildlife-livestock is the base outcome.

Table 9: Results of the multinomial logit choice Model

Variable	Specialized Wildlife Ranches	odds ratio	Mixed Ranches	odds ratio
Membership	-0.160	0.852	0.216	1.241
	(0.223)	(0.19)	(0.162)	(0.201)
Asset (Not including land).	-0.100	0.905	0.457**	1.580**
	(0.260)	(0.235)	(0.202)	(0.32)
Annual Mean Temperature	-4.592***	0.010***	-4.083***	0.017***
	(1.169)	(0.012)	(0.978)	(0.017)
Annual Mean Temperature Squared	0.147***	1.158***	0.124***	1.132***
	(0.034)	(0.039)	(0.029)	(0.033)
Annual Mean Precipitation	0.321***	1.379***	0.194***	1.214***
	(0.045)	(0.062)	(0.035)	(0.043)
Annual Mean Precipitation Squared	-0.002***	0.998***	-0.002***	0.998***
	(0.001)	(0.001)	(0.000)	(0.000)
Soil: Fluvisols	0.829***	2.291***	0.730***	2.074***

	(0.304)	(0.696)	(0.220)	(0.456)
Soil: Ferralsols	-0.295	0.744	0.270	1.309
	(0.495)	(0.368)	(0.444)	(0.581)
Soil: Lixisols	1.943***	6.981***	1.084***	2.957***
	(0.375)	(2.615)	(0.234)	(0.693)
Soil: Luvisols	-0.483	0.617	0.327	1.387
	(0.322)	(0.199)	(0.232)	(0.322)
Soil: Durisols	-0.925**	0.397**	-0.401	0.67
	(0.369)	(0.146)	(0.343)	(0.23)
Large Farm	0.283	1.327	0.726*	2.067*
	(0.509)	(0.675)	(0.379)	(0.784)
Constant	25.81***	1.619e+11***	27.40***	7.940e+11***
	(9.894)	1.60E+12	(8.002)	6.35E+12

Note: Base category is livestock Ranches: All predictors at their mean value and Standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 10: Marginal effects on the probability of each system (%)

	Wildlife Only (%)	Mixed Ranches (%)	Livestock (%)
Baseline Probability	13.06	59.16	27.78
Temperature (1^0C) increase	1.24	3.92	-5.15
Precipitation (1%) decrease	0.03	0.07	-0.07

Table 11: Conditional Net Revenue estimation

Variable	**Wildlife**	Std. Err.	**Mixed Ranches**	Std. Err.	**Livestock**	Std. Err.
Summer: Temperature	0.816	(1.103)	0.714	(0.625)	2.039***	(0.769)
Summer: Temperature squared	-0.013	(0.019)	-0.015	(0.011)	-0.037***	(0.013)
Winter: Temperature	0.173	(0.428)	-0.492	(0.335)	1.013*	(0.529)
Winter: Temperature squared	-0.011	(0.012)	0.018*	(0.011)	-0.007	(0.014)
Summer: Precipitation	0.080***	(0.019)	0.084***	(0.015)	0.081***	(0.021)
Summer: Precipitation squared	0.007	(0.005)	0.011**	(0.004)	-0.021***	(0.007)
Winter: Precipitation	0.088	(0.091)	-0.05	(0.032)	-0.093**	(0.045)
Winter: precipitation Squared	0.002	(0.002)	0.001	(0.001)	0.002**	(0.001)
Soil: Lixisols	-2.399***	(0.896)	1.623***	(0.46)	1.791***	(0.58)
Soil: Luvisols	-0.34	(0.474)	0.206	(0.477)	-0.339	(0.542)
Soil: Durisols	0.142	(0.142)	0.266**	(0.123)	-0.303	(0.246)
Large Farms	3.349***	(0.79)	3.575***	(0.97)	3.559***	(0.799)
_m0 (wildlife-only Ranches)			10.04***	(2.425)	14.53***	(2.069)
_m1 (mixed Ranches)	-4.820***	(1.191)			3.352	(2.048)
_m2 (livestock-only Ranches)	-6.039**	(2.957)	-4.822*	(2.837)		
rho0	0.237**	(0.116)	1.407***	(0.27)	1.716***	(0.116)
rho1	-0.933***	(0.237)	-0.016	(0.05)	0.396	(0.244)
rho2	-1.169***	(0.429)	-0.676*	(0.377)	0.023	(0.08)
Constant	-15.64	(17.0)	-0.099	(7.584)	-27.32***	(10.32)

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1: All predictors at their mean value. Note: The figures in brackets are standard errors. _M1, _M2, and_M3, are the BFG equivalents for the Mill's ratio, related to the wildlife, Mixed Ranches and Livestock ranches respectively.

Table 12: % increase in the probability of land use change

		CGCM2 2050	CGCM2 2100	PCM 2050	PCM 2100	HadCM3 2050	HadCM3 2100
Mixed Ranches-Wildlife	Temperature	6	16.5	4	9.5	18.5	17.5
	Precipitation	3.1	6.1	8	15.5	7.2	12.2
Livestock Ranches-Wildlife	Temperature	28.2	69.7	18.1	43.7	37.5	74.2
	Precipitation	9	19	5	10	22	35
Livestock Ranching - Mixed Ranching	Temperature	6.25	15.61	3.99	9.71	16.65	16.7
	Precipitation	0.7	1.2	0.3	0.6	1.15	2.3

Note: These are percentage changes.

Table 13a: Regional impact of climate change on land use decision (2050)

Province		CGCM2 2050		PCM 2050		HadCM3 2050	
		Mixed	Livestock	Mixed	Livestock	Mixed	Livestock
Eastern Cape	Temperature	7.2	12.5	4.5	8	2.5	16.5
	Precipitation	4.4	5.4	2.5	3	23.5	24.5
Limpopo	Temperature	3	8.5	4	11	9.1	16
	Precipitation	2.4	3.4	1.4	1.9	14.8	15.8
Northern Cape	Temperature	7.4	12	4.9	8	7.1	6
	Precipitation	3.3	5.2	1.7	2.9	20.4	24.4

Table 13b: Regional impact of climate change on land use decision (2100)

Province		CGCM2 2100		PCM 2100		HadCM3 2100	
		Mixed	Livestock	Mixed	Livestock	Mixed	Livestock
Eastern Cape	Temperature	14.1	26	9.5	18	14.7	28
	Precipitation	9.4	11.4	5.2	6.4	15.8	19.1
Limpopo	Temperature	6.7	17	9	23	14.1	36
	Precipitation	5.2	7.3	2.9	4.2	8.6	11.5
Northern Cape	Temperature	15.1	26.4	10.8	18	16.8	27.8
	Precipitation	6.9	11	3.5	6.2	13.3	18.1